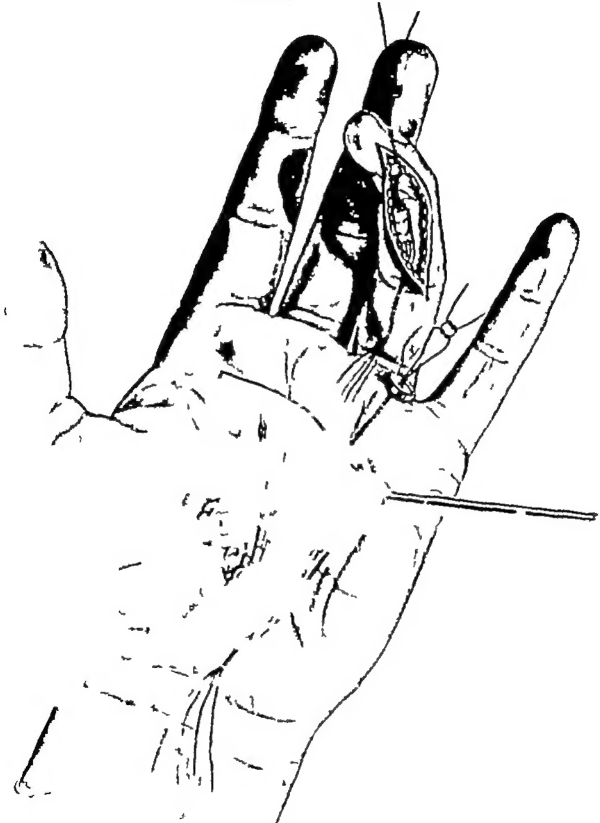
PLATE 1



SURGERY OF

THE HAND

BY

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THIS PRINTING CONTAINS SEVERAL NEW OR REPLACEMENT ILLUSTRATIONS AND MINOR TEXT CHANGES. IT IS NOT A NEW EDITION

PRINTED IN THE UNITED STATES OF AMERICA

TO

ELIZABETH BUNNELL,

MY WIFE

PREFACE TO THE SECOND EDITIO

In the last three years hand surgery has so progressed that it is necessary to make a second edition of this book It was my good fortune to have been in close touch with the reconstruction of about 20,000 hands of our soldiers in the late war, serving as the Consultant in Hand Surgery to the Surgeon General, U S Army Major General Norman T Kirk recognized the importance of salvaging hands to restore men s usefulness, and established a Hand Service in each of the nine Army General Hospitals that were assigned as centers for plastic surgery In these, teams of officers were developed so that they restored to usefulness thousands of hands that otherwise would have remained crippled Following the principles on which this book is based, they proved the value of hand surgery by the excellent results obtained by many different surgeons At the many hand conferences attended by officers from surrounding hospitals, four or five thousand hands were examined and openly discussed by many Varied and valuable were the multiple suggestions All information gained in each hospital was passed on to the others so the knowledge was pooled among all This information has been incorporated in this second edition

In the mass production of these systematized hospitals it was thoroughly demonstrated that hands should be treated as an entity, and it is hoped that this classification, the merits of which have been so proved in this war, will be perpetuated Best results were not obtained by passing the hand from one tissue specialty to another The specialty aspect of the hand is more regional, like that of the eye and the ear It necessitates training in correlation

nerves, tendons, mechanics and bio the working unit, function as a who the social aspect

Both the subject and the number geons interested in it are rapidly gr The field seems endless in its e Much that is new and from many will soon be published In 1946 the can Society for Surgery of the Har formed The bulk of orthopedic relates to the back and lower only a small proportion being with the upper extremity and still le the hand The hand, however, is portant. In man, the purpose of the extremity is to place its most im part, the hand, where it can work nerves of the arm are to activate the Hands are most valuable and impor all of us and to the manual worker means of living

In spite of this, surgery of the h late in developing Surgery of th started much earlier with tenotomi wrenchings, unsuitable to the hand surgery lagged, surely not from i portance, but probably because it ticulous and complicated As a co part, in the progress of art, hands a were pictured early as flippers, ofte out interdigitation until the time Greeks who, for a short time only, eled them well Properly formed again appeared in the Renaissance fifteenth century, and artists ever have portrayed them realistically

In this second edition, the main ciples have been scarcely altered, bu siderable new material has been mostly to the chapters on reconstr injuries infection and tumors Th

PREFACE TO THE SECOND EDITION

always changing and advancing As did chemotherapy, new discoveries will open new fields

To Surgeon General Kirk I feel a debt of gratitude for having given me the opportunity to serve as the Consultant in Hand Surgery

I feel greatly indebted to the officers of the U S Army, who did the work of hand reconstruction, for their wonderful co-operation and their many valuable suggestions Of these officers, for their extreme courtesy in contributing many photographs of their work, I feel especially grateful to Doctors S B Fowler, Wm. H Frackelton, Walter C Graham, L. D Howard, Gilbert L Hyroop, Wm Krigsten, James W Litler, Walter B Macomber, Geo S Phalen Donald R. Pratt and Darrel T Shaw

Special thanks are due my associate Doctor L D Howard, for his co-operation and his revision of the chapter on tumors

I am also thankful to Mrs. Helen Loran for her careful work in typing the manuscript, to my wife for her co-operation, and to Mrs. Rosebud Preddy for some additional drawings

September 1, 1947

STERLING BUNNELL, M.D

PREFACE TO THE FIRST EDITION

We are now in a mechanized age, which means that millions of hands will be injured It might be called the Age of Trauma With the speed up of industry and with mechanized warfare the manual worker will, from the very nature of his work, injure his hands Hands lead the list of industrial accidents and are responsible for a large portion of compensation expense From a social standpoint the functioning of this valued member is of vital importance to the manual worker for his very livelihood

From an evolutionary aspect, our hands when we became bipeds were relieved from the duty of locomotion and were then free to develop into more useful instruments By brains and hands man excelled over all other species, for other animals had as weapons only hoofs, claws, or teeth, while the hand of man could grasp any weapon The brain developed the hand, but it is also true that in each one of us many of our mental processes have developed from the feeling and movement of our hands In the case of the brilliant Helen Keller, both deaf and blind, her whole life was opened up through her hands The special development of the human hand is largely responsible for the great handicraft of man

The hand is so intimately rooted into our lives, thoughts, and expressions that it has become a part of our language, as evidenced by the following handle, handy, second hand, to give the hand in marriage, all hands on deck, rule with a strong hand, at hand, on hand From the Latin *manus* are derived manage, management, mandate, manipulate, maintain, manner, manuscript, manufacture, from the Greek *cheiro* come the French word *chirurgie* and our English surgery

Although the hand is composed mainly of tough material, it also includes exact machinery of much refinement and tissues of great delicacy and specialization Such a mechanism is readily wrecked by trauma and infection, and it is little wonder that hands mangled by trauma, or those infiltrated and gutted by infection, later present difficult problems in reconstruction After tendons and nerves have sloughed and the storm of infection is over all of the tissues contract, resulting in flexion contractures, and the movable parts become bound with cicatrix into a congealed hand Much of this disability may be spared by correct early treatment of infections and injuries

Malformation, injury, and infection swell the ever-coming stream of crippled hands needing repair To recondition these members successfully is difficult. Surgical reconstruction of the hand requires specia careful technic to minimize adhesion formation which is so prone to bind togethe the nicely adjusted movable parts It is composite problem requiring the correlatio of the various specialties—orthopedics, plastic and neurologic surgery—the knowledg of any one of which alone is inadequate fo repairing the hand Trauma involves a types of tissue, irrespective of the artifici divisions of our specialties Usually in th same traumatized limb with flexion co tracture, injury to tendons, bones, joint and nerves, we must combine plastic, orth pedic, and neurologic surgery As the prol lem is composite, the surgeon must also b It is impractical for three specialists work together or in series. There is shortcut. The surgeon must face the s uation and equip himself to handle any a all of the tissues in a limb

In hand surgery the structures encou

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PART FOUR

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PART ONE

THE HAND

1

Phylogeny and Comparative Anatomy

ORIGIN OF LIMBS

Inquiry into the origin of hands leads us down the animal phyla until we find the beginning of limbs in the primitive sharks Here is the first sign—a lateral fold on each side, continuous from gill to anus, into which muscles grew in later development. The middle of each fold receded but the two ends increased, so that it became the established order throughout all fishes to have two pectoral fins just behind the gills and two pelvic fins near the anus. Since then this tetrapod or four limbed architecture has persisted through all consecutive classes—amphibians, reptiles, and mammals —up to man.

PHYLOGENETICS OF INTRINSIC MUSCLES OF HAND

From a search through the literature and by dissection of the hands of reptiles, mammals, monkeys, higher apes, and man for the origin of the intrinsic muscles, the author has reached the following conclusions of all the muscles of the upper extremity the intrinsic ones of the hand are primordial. They date back to the early fish where there was no arm but only a pectoral fin, the forerunner of the hand Thus, the hand in phylogeny preceded the arm, which developed later from higher cervical segments The fish has not yet a neck, the bones of the pectoral fin articulating with the skull Our intrinsic muscles are still supplied by the lower two nerves of the brachial plexus, and nerves remain true to their muscles The arm developed lat from the neck for terrestrial existence.

Earliest Intrinsic Muscles Moved Fin Rays. The tetrapod or four limbed arrangement which became standard had its forerunner in the fish with pectoral and pelvic fins The independent muscle of the rays of the pectoral fin was made possible by the anlage of our intrinsic hand muscles Watching pectoral fins in an aquarium, one sees versatility of movement as the fins are continually fanning water A wave of movement may run down or up a pectoral fin causing the fish to or descend as if the fin were geared to t water One of the earliest fishes that persists and is closely allied to the early shark is the skate, which swims along by graceful undulations of its wings, which merely glorified pectoral fins. The that move these rays in fins are the of the intrinsic muscles of the hand

Origin of Pentadactylism. In the velopment from fish through amphibians man, the multirayed fin of the fish was duced to the pentadactylate type. It generally conceded that it was the

erygian fish called "fringed fins," the forerunners of the lung fishes, which emerged from the water, evolved to Amphibia, and developed lungs and feet for terrestrial existence. Some lung fishes that persist today use their pectoral and pelvic fins in walking

Fossils from upper Devonian in Pennsylvania prove that the fringed fin fishes had jointed pectoral fins, each with an axis fringed with a series of soft rays In the step from these fishes to the Amphibia, according to W K. Gregory, the most proximal segment of the stubby bones at the base became the humerus and the next two segments became radius and ulna. The next several segments still dividing developed into the carpus. The main stem became the thumb and the bones on the ulnar side became the other four digits. From the digit bones the many soft rays extended The resulting pentadactylism persisted through the ages, with recession in some instances in various forms of amphibians, reptiles, and mammals.

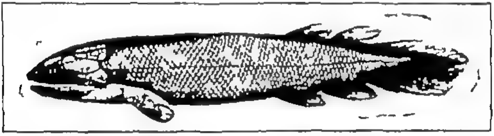


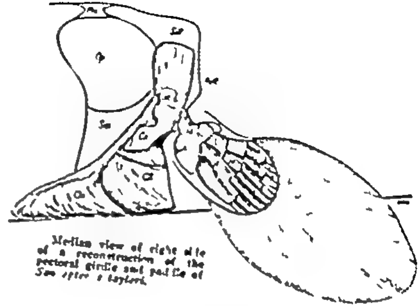
FIG. 1 Following the sharks and just before the lung fishes, came the Crossopterygii or fringe fins, with fleshy jointed fins. It is conceded that this is the subclass which emerged from the water to become amphibia, and developed lungs and limbs for terrestrial existence. (Reproduced from "Fishes" by David Starr Jordan by courtesy of D Appleton Century Co., Inc.)

From the above it is apparent that the hand developed before the arm and from its very beginning contained intrinsic muscles. Muscles in fish are largely undifferentiated and are arranged in segmental myotomes. Those in the pectoral fin are developed from modification of the adjoining myotomes.

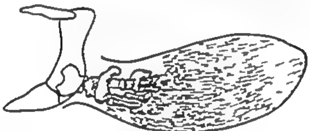
Intrinsic Hand Muscles Well Developed in Amphibia. The intrinsic muscles of the hand are found to be already highly developed in the Amphibia and in this class they have sole control of the digits As yet no forearm muscles move the digits, all extensors and flexors of the digits being of the "brevis" type, their origin not reaching above the carpus The same high development of intrinsic muscles runs through Reptilia, and even here the long flexor profundus is the only forearm muscle which has joined to the intrinsic muscles across the carpal ligament so as to move the digits

Long Forearm Muscles Assume Control of Digits. All other forearm muscles at this stage did not insert below the carpus or metacarpals. It was an easy step, therefore, in the gradation to mammals for this tendinous attachment or connection across the carpus merely to loosen from the carpus, with the result that the long muscles in the forearm became continuous with the brevis muscles in the hand. This is apparently the development of the long extensors and long flexor sublimis and profundus in man which now control our digits from the forearm. Recently the author had three patients who had one and two slips of the atavistic extensor brevis In the human foot there is still an extensor brevis, and the flexor sublimis is a brevis. Thus we see that the hand developed before the arm and that the intrinsic muscles of the hand were primordial, some of them joining later with the forearm muscles to become long extensors and long flexors. All in-

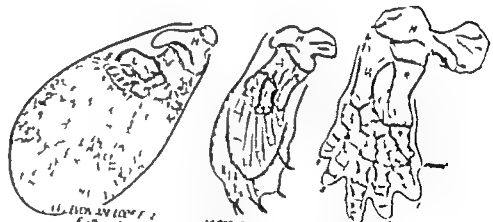
Original specimen of a pectoral fin of the fringe-fin fish, *Sauripterus taylori* Hall, from the upper Devonian of Pennsylvania—the conceded ancestor of the amphibia and all the vertebrates that followed.



Median view of right side of a reconstruction of the pectoral girdle and paddle of *Sau. after s. taylori.*



Comparison of pectoral girdle and limb of a crossopterygian fish with that of eryops of the stegocephalian type, the earliest known amphibian showing homologous parts, according to Romer's theory



Transformation from the multirayed crossopterygian paddle to the pentadactylate hand of eryops and all subsequent vertebrates.

FIG. 2 Drawings show the story in fossils of how the pectoral fin of this early crossopterygian developed into the forelimb of the earliest known amphibian, eryops, thus changing from the multirayed fin to the five-digit type (After W K. Gregory Reproduced by courtesy of The American Philosophical Society)

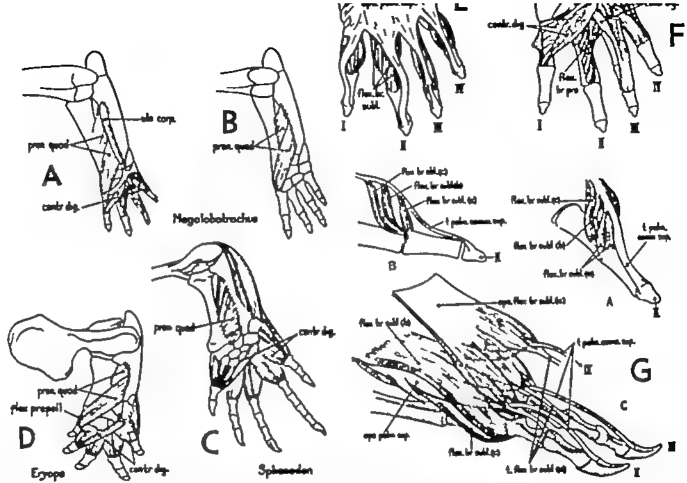


FIG. 1. (A-D) Intrinsic hand muscles are well developed in amphibia, and, in fact, are the only muscles that control the digits. The arm muscles stop at the carpus or metacarpus. The arm developed after the hand from higher cervical segments. The intrinsic muscles in man are supplied by the lower segments of the eighth cervical and the first thoracic nerves, and the arm by higher segments up to the fifth cervical. The surprising development of the intrinsic muscles in amphibians is shown in this dissection of the hand of the giant salamander of Japan, megalobatrachus.

Comparison of the deepest layer of forearm muscles and the contrahentes digitorum of megalobatrachus with those of the reptile sphenodon, and their inferred restoration in eryops.

(E) Dissection of the hand of megalobatrachus showing superficial flexors and their attachment to the palmar fascia.

(F) Showing deep flexors and their relation to the ulnocarpalia.

(G) Dissection of the second digit of megalobatrachus (*A* and *B*) and of the second, third, and fourth digits in the reptile sphenodon (*C*) to show the relation of the digital flexors to the palmar aponeurosis. (After R. W. Miner. Reproduced by courtesy of the Bulletin of the American Museum of Natural History.)

Fig. 4 A.

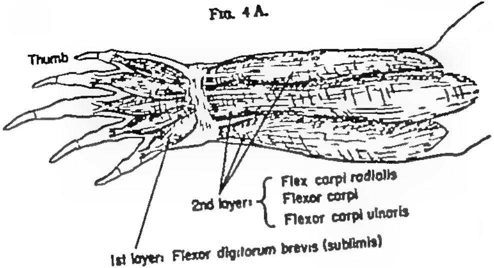


Fig. 4 B

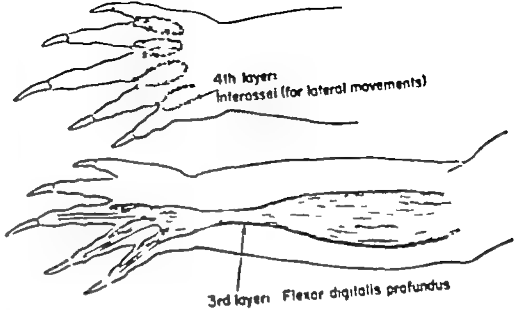


Fig. 4 C

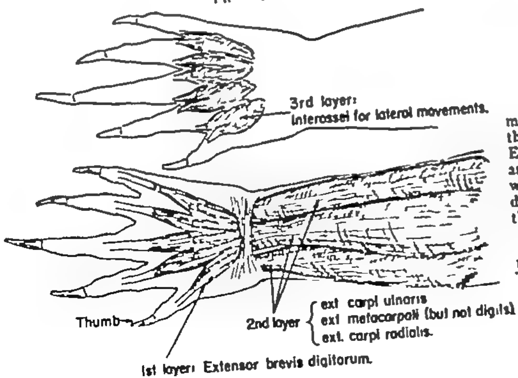
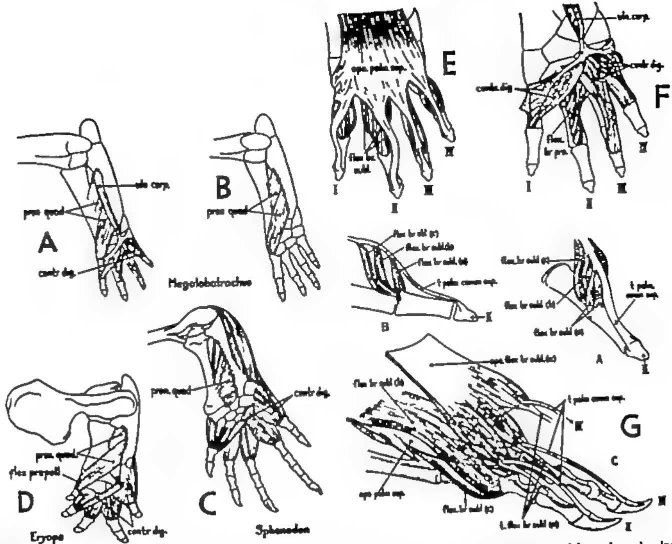


Fig. 4 A Ventral view of right foot of an alligator
In reptiles, as in amphibians, the hand is thick and meaty from intrinsic muscles. All muscles controlling the digits are of the brevis type except the long flexor profundus—the only forearm muscle which acts on the digits. Even it is still bipartite In the gradation to mammals, the extensor brevis and flexor sublimis became long muscles by fusing end to end over the carpus with the forearm muscles and then separating from the carpus. The predominance of the intrinsic muscles in reptiles is shown in these sketches from the hand of an alligator

Fig. 4 B Ventral view of right front foot of an alligator

Fig 4 C Dorsal view of right front foot of an alligator (Courtesy Journal of Bone and Joint Surgery)



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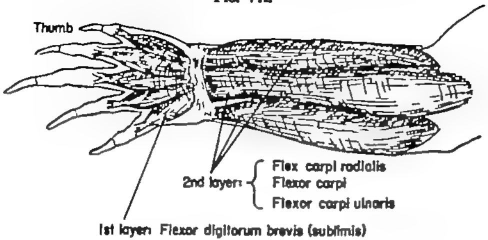

Fig. 4 B

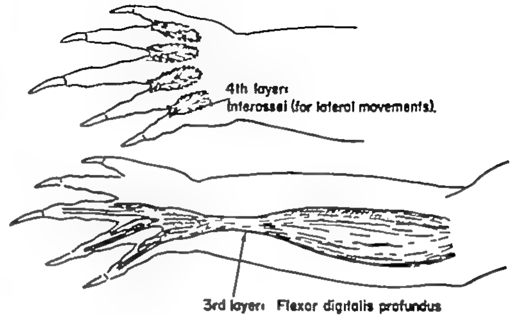

Fig. 4 C

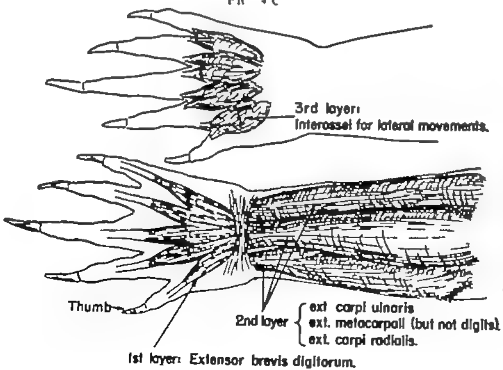

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Fig. 4 B Ventral view of right front foot of an alligator

Fig 4 C. Dorsal view of right front foot of an alligator (Courtesy Journal of Bone and Joint Surgery)

trinsic muscles in the hand are supplied by the eighth and first spinal segments The arm, which has a higher segmental nerve supply as we ascend to biceps and deltoid muscles, developed later from the side of the neck at higher segmental levels.

Intrinsic Muscles of Hand from Amphibia Through Primates. The many layers of muscles and tendons in the hand

FIG. 5 Pectoral girdle and cartilaginous fin skeleton of fish (Scyllium) c, coracoid region g, glenoid surface ms, mesopterygium mt, metapterygium r radialis s, scapular region. (Courtesy Kingsley J S Comparative Anatomy of Vertebrates, The Blakiston Company Publishers.)

of the Amphibia (six) have been consecutively traced by McMurrich and others in their gradual modification through reptiles (eight) and mammals to man, who has only five layers in the palm In mammals the intrinsic muscles persisted well in those which used their front extremities as hands. Some interosseous muscles became specialized, as in the cat tribe, to retract and erect the claws

In monkeys and higher apes the intrinsic muscles of the hand are well developed, and their arrangement is so similar to that of man that the variations are small and rather exceptional. The four or five contrahentes of most mammals and monkeys, which are separated from the interossei by the deep branch of the ulnar nerve have been reduced in man to just the adductors of the thumb The contrahentes have origin in the carpus and metacarpal bases. They insert on the metacarpal heads and proximal phalanges and adduct toward the third metacarpal In monkeys the second to fifth are often absent. The second, fourth, and *fifth are poor in gibbons, and absent in gorillas, orangoutang, and man. The chim*panzee has only the first, fourth, and fifth.

Palmar interossei in most mammals number six or seven, in primates five or six, but in man there are only three because four have fused with the dorsal interossei, thus accounting for the latter's double insertion.

In primates the palmar interossei and lumbricales insert in the lateral expansion of the extensor tendons, and the dorsal interossei insert only on the phalanges. The axis of the interossei in man and most primates is the third digit, but in some prosimians it is the fourth.

The lumbricales in primates are variable in number and in the number of their heads, and may have accessory fasciculi. In most they are radial and four in number, the outer two being supplied by the median and the inner two by the ulnar nerve.

PECTORAL GIRDLE

With the necessity for mobility in the primitive vertebrates came the two girdles, pectoral and pelvic, the first just behind the last gill and the second just in front of the anus. These at first were to furnish scaffolding for muscle attachments to move the fin and finally the limb Later, in the Amphibia when the pectoral girdle separated from the skull and spine, it became movable on the trunk by muscle attachments.

Fishes. In the early fishes the pectoral girdle, like the pelvic girdle, was simple and U shaped It formed outside the main body or myotomes. Later, nerves to the limbs grew past it and through it. Each side of the girdle was of two parts—the dorsal

one, the scapula, the ventral one, the cora coid—and between them was the glenoid cavity which articulated with the limb The two coracoids were attached to each other by membrane or an intermediate bone. There developed an omovertebral fied to become a trident, the ventral por tion expanding broadly with a foramen through it or dividing into precoracoid and coracoid, with the foramen formed between them and their union with the sternum This change into bipartite coracoid also oc-

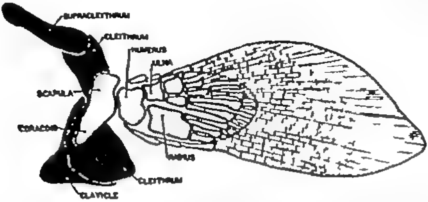


FIG. 6 Pectoral girdle and fin of Sauropterus an upper Devonian crossopterygian fish. Interest in this type of fish fin lies in the similarity of relations of the proximal elements of the extremity to those found in the pectoral extremity of the tetra pods. (Drawn after Brown, Neal & Rand Comparative Anat omy The Blakiston Company)

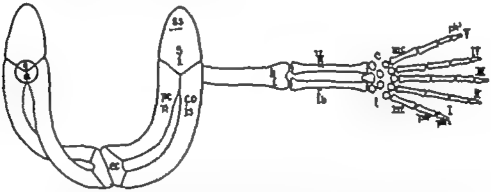


FIG. 7 Diagram of tetrapod girdles and free appendages, posterior view Upper letters, pectoral, lower pelvic appendages *a*, acetabula *c*, carpus *co*, coracoid, *ec*, epicoracoid (no equivalent in pelvis) *f* femur *fi*, fibula *g*, glenoid fossa, *h*, humerus *i*, ileum *is*, ischium *mc*, metacarpus *mt* metatarsus *p* pubis *pc*, precoracoid *ph*, phalanges, numbered *r*, radius *s*, scapula *ss* suprascapula (no equivalent in pel vis) *t*, tarsus, *tb*, tibia *U*, ulna *T V* digits. (Courtesy J S Kingsley Comparative Anatomy of Vertebrates, The Blakiston Company)

bone and a suprascapula for attachment to vertebrae and skull. The clavicle developed from the skin and in different fishes many subplates developed, but in all there was the main ventral part, the coracoid, and the dorsal part, the scapula with the limb springing from between them.

Amphibia. As amphibians emerged from the water accommodating to the need for terrestrial locomotion, the girdle modi curred in the pelvic girdle and here is still retained, the ilium being the dorsal part and the pubis and ischium the ventral The obturator foramen corresponds to the cora coid foramen

In the early amphibians, Eryops of Stego-cephalia type, there were a scapula, cora coid, clavicle, interclavicle, and also a cleithrum articulating between the supra scapula and the skull. This latter, how-

ever, with the need for a more mobile head and girdle, disappeared in all later amphibians, thus allowing the scapula to descend and liberating the head for free movement. This descent of the scapula is rehearsed in each human embryo The median interclavicle was lost in some amphibians, but retained in others, and was passed on to the reptiles In most amphibians, the clavicle fused with the precoracoid.

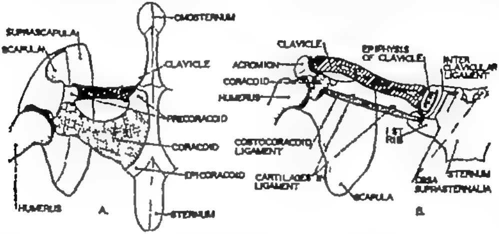


FIG. 8 Diagrams illustrating the fundamental similarity of the human (B) and amphibian (A) pectoral girdle. In man the coracoid element has degenerated into a process (coracoid) and a connective-tissue ligament, containing occasionally cartilage. (Redrawn after Huntington, Neal & Rand Comparative Anatomy The Blakiston Company)

The frog, which lands so hard on his front legs and chest, developed for this a very large broad girdle with flat, overlapping, platelike coracoids, epicoracoids, pre-

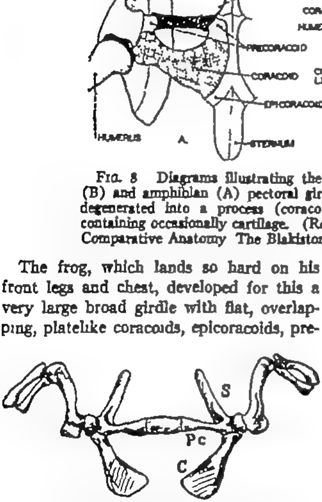


FIG. 9 Pelvic girdle of Southern Snapping turtle. *S* scapula, *Pc*, precoracoid, *C* coracoid.

coracoids, and clavicles, the coracoid and precoracoid being joined by a bar A large proportion of the specialized parts of the various girdles were cartilaginous.

Reptiles. The reptiles retained the trident girdle. There usually was a foramen through the coracoid, though in some the foramen was formed by the presence of a precoracoid. The parts became more bony and differentiated for greater activity The humerus, as in all vertebrates, sprang from the glenoid at the juncture between the scapula and coracoid. The plate-like character of the interclavicle, sternum, and broad coracoid and epicoracoid remained, as these animals largely slid along on the ground. In the turtle the scapula is just a little spike extending backward, and diverging forward from it as a Y is the coracoid and the clavicle fused with the large precoracoid. The crocodilia have just a broad coracoid, interclavicle, and scapula. In snakes both girdles have been lost, though some remnants of the pelvic girdle are still to be found in the python, consisting of two rudimentary clawed bones.

Birds. Here there is special tremendous development of the keeled sternum for origin of pectoral muscles for flying The scapula is firmly fixed to the sternum by a rod-like prop, the coracoid, and is also braced to it in front by the clavicle. The two clavicles are fused to each other at their sternal attachment, thus forming the wish bone The scapula is but a small curved rod extending down the back for muscle attachment. The bird in flight lifts him-

self by his sternum through his pectoral muscles. Some of the moas, which are flightless, have even lost all vestiges of the upper limb and pectoral girdle The early prehistoric toothed bird, Archaeop-

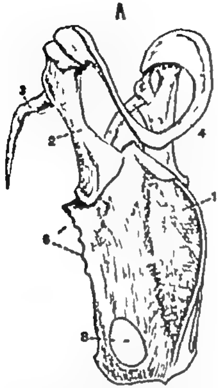


FIG. 10. Shoulder-girdle and sternum of a black vulture (*Vultur cinereus*) × ½. (Cambridge Museum) 1 carina of the sternum 2 coracoid 3 scapula 4 clavicle, 6 surfaces for articulation with the sternal ribs 7 xiphoid processes 8 fontanel. (Courtesy Reynolds Sidney H. The Vertebrate Skeleton, Cambridge University Press 1897)

teryx, had a pectoral girdle much like that of a reptile, and unlike other birds had a foramen through the coracoid.

Mammals In the amphibians and reptiles, largely belly draggers, the breast plate was large with strong coracoid attachments. This applies also to birds, as their sternums are weight bearing Mammals, however, walk, supporting their weight on their limbs, not on their sternum, and their limbs are more movable Therefore, they have lost all coracoid attachments to the sternum and in many without clavicles the girdle is completely free from bony attachments The coracoid process has become unattached, short, and rudimentary It still, though, retains ligamentous attachment to the sternum through the costocoracoid ligament and occasionally pieces of cartilage are found in this As the weight is transmitted through muscle attachments to the scapula this bone is highly developed in mammals The acromion is large and is prolonged as the spine of the scapula. The clavicle, when present—the only bony connection of the shoulder girdle to the ster-

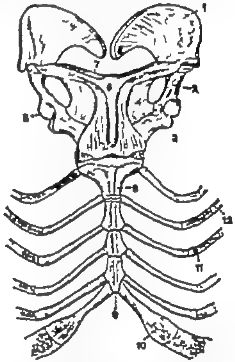


FIG. 11 Ventral view of the shoulder girdle and sternum of a duckbill (*Ornithorhynchus paradoxus*) × ¾. (After Parker) 1 and 2 scapula 3 coracoid 4 precoracoid 5 glenoid cavity 6 interclavicle, 7 clavicle 8 presternum 9 third segment of mesosternum 10 sternal rib 11 intermediate rib 12 vertebral rib (Courtesy Shipley A. E and E. W MacBride Zoology—An Elementary Text book, Cambridge University Press England By permission of The Macmillan Company publishers New York.)

num—is still attached to the coracoid process by the conoid and trapezoid ligaments, which are all that remain of the primitive precoracoid fusion of the clavicle The clavicle is attached mainly to the acromion. The clavicle commenced in fishes, was pres-

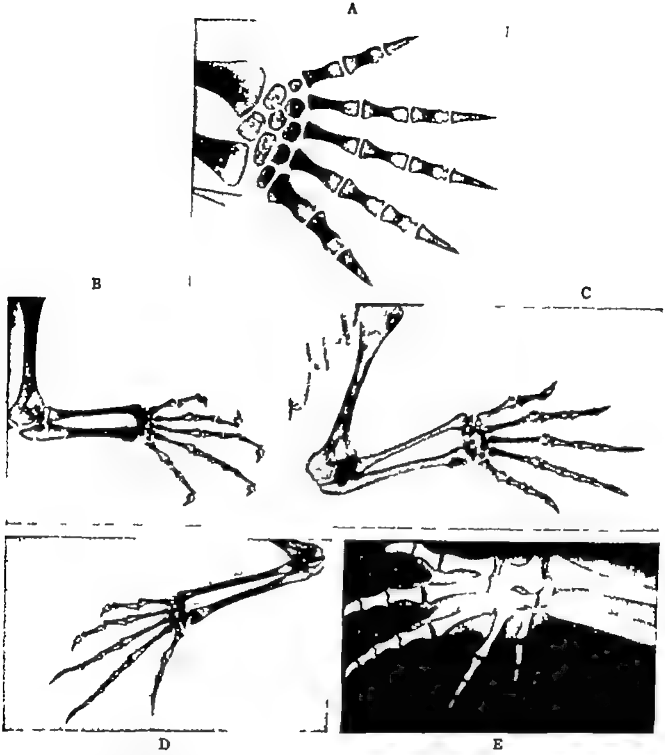


Fig. 12 Bones of hands of reptiles.

(A) Florida turtle. Primitive type of hand, radiale, intermedium ulnare os centrale, and carpals five. Phalangeal formula 2 3 3 3 2 differing from the primitive type of 2 3 4 5 3

(B) Chuckwalla. Fairly primitive types of hand, Phalangeal formula is typical of reptiles 2 3 4 5 3

(C) Crested lizard. Fairly primitive type of hand. Phalangeal formula is typical of reptiles 2 3, 4 5 3

(D) Collared lizard. Fairly primitive type of hand. Phalangeal formula is typical of reptiles 2 3 4 5 3

(E) Alligator Carpals reduced by synostosis to three. Phalangeal formula 2 3 4 4 2

The carpus has been modified the most in mammals that bear weight on the digits The Amphibia and reptiles were planti grade. In primates the carpus has changed but little from the primitive pattern The os centrale, though present in the embryo of most mammals, fuses with the scaphoid before birth In man it appears in the sixth week and fuses in the eighth Carpals

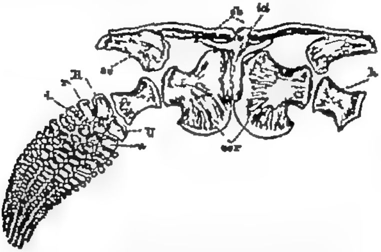
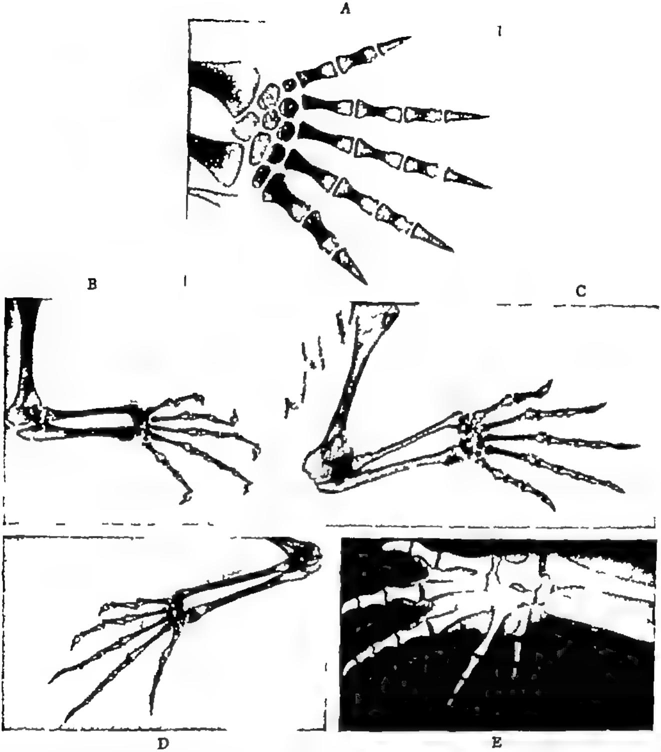


FIG. 13 *Ichthyosaurus communis,* Conyb. Lower Lias England. Pectoral arch and right forelimb ventral aspect, ¼. *cl,* clavicle *cor,* coracoid *h* humerus *i,* intermedium *id,* interclavicle (partly covered by clavicles) *R,* radius *r* radiale *sc,* scapula *U* ulna *u* ulnare. (After Zittel Karl A., Palaeontology from Goodrich Edwin S Studies on the Structure and Development of Vertebrates, 1930. By permission of The Macmillan Company publishers.)

IV and V have fused in mammals, includ ing man, to become the unciform. In primitive mammals there were three car pals and a pisiform in the first row and four in the second Due to bearing weight longitudinally through the carpus more of them fused or became lost. The scaphoid and lunate support the radius and the cunei form supports the ulna. The scaphoid rests on the trapezium, trapezoid, and part of the os magnum, the lunate rests on the os mag num and usually also on the unciform, and the cuneiform on the unciform. In all car nivora, including seals and sea lions, the scaphoid and lunate are fused, and in the hoofed animals the trapezium is lost. In the primitive pattern the trapezium, trape-zoid, and os magnum rest each on one meta carpal and the unciform on the fourth and fifth, but this modifies as the number of metacarpals is reduced

The pisiform is not a true carpal, having developed as a sesamoid bone in a tendon at least as far back as in the reptiles In crocodiles and in most mammals it articu lates also with the ulna In the carpus of most quadrupeds and also higher apes, the pisiform stands out as the most conspicu ous bone. This and the tubercle of the scaphoid project for great muscle leverage in running, but the pisiform is rudimentary in man.

Digits and Phalanges AMPHIBIANS AND REPTILES The primitive hand had five digits, but in all except the earliest Amphibia these have reduced to four or in some three, though five in the foot. Throughout the reptiles, pentadactylism prevails, though in some of the dinosaurs, such as the ferocious Rex tyrannosaurus, there was a reduction to three. The num ber of phalanges on each digit is distinc tively quite constant in reptiles The for mula commencing with the thumb is two—three—four—five—four in the manus, and two—three—four—five—three in the pes. Crocodilia are an exception, with a formula



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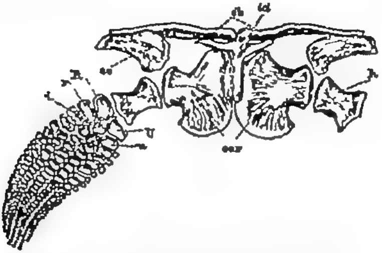

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of two—three—four—four—three. There are also some that reverted into the sea, the marine reptiles, in which the number of phalanges was greatly increased. The arm and carpal bones became short and flat, and the digits joined in a paddle resembling a fin. It was quite unlike that of a fish and definitely a reversion of limb bones. One of these, the Ichthyosaur, had as many as nine digital rays and totaled a hundred phalanges, there being up to 26 in the third flying, like an aileron, or a boatman hold ing back with one oar

The turkey buzzard has a claw on the thumb and the ostrich one on the thumb and index. The cassowary has a formi dable claw on its single digit. One of the earliest known toothed birds, the Archaeopteryx, had three long, separate, well formed digits, each with a claw. The young of the modern hoatzin of South America are born with a large claw on the thumb

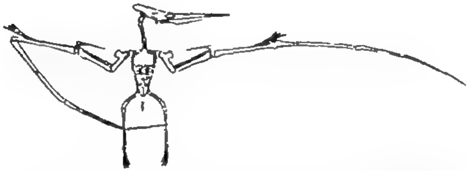


FIG. 14. Pterodactyl skeleton (Nyctodactylus). Wingspread eight feet. Large deltoid attachment. What appears to be a recurved thumb is calcification of ligament. Main wing ray is the fourth, the fifth being absent. (Courtesy Williston, S W Amer Jour Anat., 1 299 1902)

digit. It is the only known species of ani mal (not a freak) to have had more than five digits.

BIRDS have an arm of humerus, radius, and ulna. Extending from their two car pal bones are three fused metacarpals and three digits. The first metacarpal is a stub supporting two or three phalanges as a thumb. The second and third metacarpals are larger, fused at each end, and support an index finger of three phalanges. The third digit springs from the side of the third metacarpal and is very short, consist ing of one or two phalanges. The primary wing feathers attach to the index phalanges and third metacarpal, and the secondaries to the ulna. The outstretched wing from the wrist distally can supinate just as from the palm-down position with arms spread we can make our finger pulps face forward without turning the forearm. This aids in and index finger, with which they climb about on the limbs. These are lost in the adults. The Hesperornis, a prehistoric toothed water bird, had lost all of its wing but a rudimentary humerus, and some of the extinct large flightless Moas of New Zealand had not a trace left of wing or pec toral girdle.

MAMMALS show the greatest variation in number of digits, the lowest in those that are the most specialized for running. Most carnivors walk on their metacarpal heads (the central pad) and their four ter minal phalanges, the thumb having been lost or reduced to a dewclaw, and the hoofed mammals on their terminal or ungual phalanges. The ungulates have been divided into odd and even-toed, the Perissodactyls and the Artiodactyls. In them, the marginal digits are those lost, the thumb being the first to go. In the odd toed the fifth digit is then lost, leaving three, of

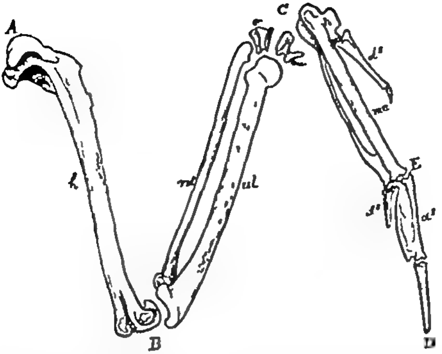


FIG. 15 Right wing bones of a duck *h* humerus *rd* radius *ul*, ulna *C* carpus *sc*, outer carpal, scapho-lunare or radiale *cu* inner carpal cuneiform or ulnare these two composing the wrist or carpus *mc* the compound hand bone or metacarpus, composed of three metacarpal bones bearing as many digits—the outer digit seated upon a protuberance at the head of the metacarpal the other two situated at the end of the bone.

d^2 the outer or radial digit, thumb of two phalanges.

d^3 the middle digit of two phalanges.

d^4 the inner digit of one phalanx.

D to *C*, seat of flight feathers or primaries *C* to *B* of secondaries (Courtesy Coues Elliot Key to North American Birds, Dana Estes and Company 1903) Legend abridged.

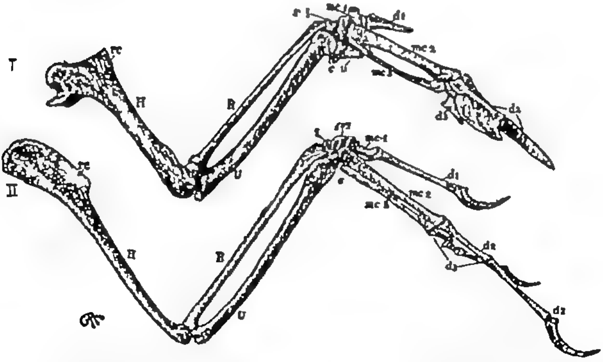


FIG. 16. Right forelimb of (I) pigeon, (II) *Archaeornis siemensi* drawn by the author from the fossil in Berlin. H, humerus R, radius U ulna c, centrale d 1–3 first to third digits i, intermedium mc 1–3, first to third metacarpals r radiale u, ulnare 1 + 2 coalesced first and second distal carpals. (Courtesy Heilmann, Gerhard The Origin of Birds, New York, D Appleton and Company 1927)

which the central or long digit is the largest as in the tapir or rhinoceros. On again losing the two marginal digits, only the middle one remains, as in the horse, in which the process can be traced from the four toed *Eohippus* of the lower Eocene. The even toed or ruminants lose the index

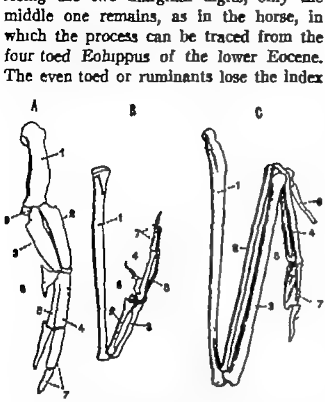


FIG. 17 Adaptations of upper extremity in birds to environment. A, penguin that flies under water B ostrich, a flight less bird and C, gannet, an able flyer In (C) the distal phalanges of the pollex and second digit have been omitted. 1 humerus 2 radius 3 ulna 4 second metacarpal 5 third metacarpal 6 pollex 7 second digit 8 cuneiform 9 sesamoid bone. (Courtesy Reynolds, Sidney H. The Vertebrate Skeleton, Cambridge University Press, 1897)

and little digits, leaving the long and the ring which form a cloven hoof The pig still has four toes, of which the two lateral ones are off the ground Most rodents have lost the thumb The phalanges in land mammals are never more than three in each digit and two in the thumb, but in whales and porpoises they may be multiple

PHYLOGENY AND DIFFERENTIATION OF MUSCLES FROM AMPHIBIA TO MAMMALS

Flexor muscles in the forearm in Amphibia were differentiated into a superficial and a deep layer The superficial layer was divided into the radiali and ulnari muscles from their respective bones, and an intermediary muscle, taking origin mainly from the inner humeral condyle. This primary differentiation has persisted, developing into the muscles of primates as follows

Of the superficial layer the radiali split into pronator teres and flexor carpi radialis *The ulnari became the flexor ulnaris* and the intermediate or condylar portion split into palmaris longus and flexor digitorum sublimis. The splitting was not quite so definite, as in some there were two or three palmaris longus muscles from the superficial parts of all three divisions, in some the sublimis came more from the ulnari and in others more from the radiali

The deeper layer, originally composed of one longitudinal and a number of deeper oblique muscles, finally reduced to the flexor digitorum profundus and the pronator quadratus.

In no amphibian, and in only a few reptiles, does any forearm muscle insert distal to the metacarpals Several layers of brevis muscles *move the digits, taking their origin* from several layers of palmar aponeurosis. The flexor digitorum profundus which inserted into this aponeurosis was first to become continuous through it with the deeper brevis group to the digits By the aponeurosis merely freeing itself from the carpus, the profundus moved the digits and that brevis muscle became the lumbricales, as shown in the alligator, Fig 4

The flexor digitorum sublimis appeared first in mammals. The arrangement of the tendons of the superficial brevis muscles, being perforated for passage of the profundus tendons, was already present as the result of the divisions of the digital slips of the aponeurosis. The belly of the sublimis muscle, split from the profundus muscle as the condylar portion, was first inserted into the palmar aponeurosis from which the superficial brevis took origin, so all that was

eeded in order for the muscle to move the igits was a separation of the aponeurosis rom the carpus and conversion of the bre is muscles into tendons The superficial revis muscles at the two borders of the and developed into the thenar and hypo-henar eminences

The extensor muscles on the dorsum of he forearm underwent similar changes

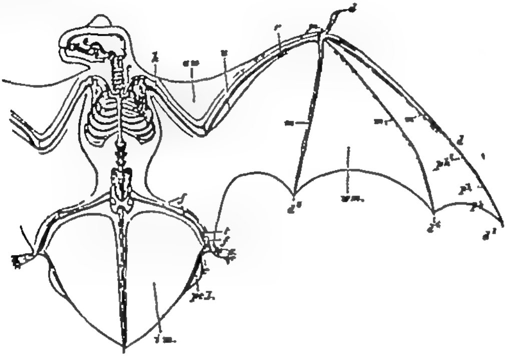


FIG. 18 Skeleton of a bat (*Vesperugo noctula*) The web spans from the tips of the digits to the foot. The thumb is free and the index and long digits, including metacarpals, are close together as the first of the three struts *u* rudimentary ulna *m* metacarpal *d 1–5* digits *ph 1–3* phalanges. (Courtesy, Flower William Henry and Richard Lydekker An Introduction to the Study of Mammals Living and Extinct, Adam and Charles Black, 1891)

They were first divided into radial, ulnar, and intermediate parts, and did not reach beyond the metacarpals. They separated from a deeper layer which eventually became the extensor proprius muscles to the digits the extensor pollicis longus and abductor pollicis longus being in series with these. The long forearm extensors joined with the brevis muscles on the dorsum of the hand that moved the digits Then on the separation of the tendons from the carpus, the long muscles assumed the duty of extending the digits The muscle bellies of the brevis became tendinous

In certain mammals such as the ungulates with a reduced number of digits and absence of pronation, supination, and lateral wrist movement, the muscles have been similarly reduced. In some, the tendon of the flexor digitorum profundus is prolonged proximally from the muscle to a bony attachment to act as a tenodesis and give a spring like recovery (horse and neurotrichus, a shrewlike mole) Most mammals have radiali, ulnari, and intermediate flexors, both extensor communis digitorum and extensor proprius to all fingers and a long abductor and extensor of the thumb, if the latter is present. In marsupials, carnivora, and moles, the palmaris longus—a muscle found only in mammals and the iguana—consists of two, one reaching to the first and the other to the fifth digit. The latter tendon, as explained by its origin, may be perforated for the passage of the profundus tendon as in the sublimis.

STRANGE SPECIALIZATION OR ADAPTATION OF *MANUS*

It is remarkable what versatility of modification for special usage the hand shows in various animals, though in each it was

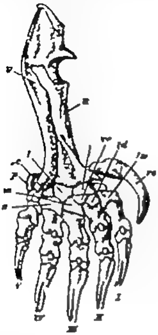


FIG. 19 Hand of mole (*Talpa europaea*) specialized for digging, with extra breadth furnished by radial sesamoid. *c* cuneiform *ce* centrale *l* lunar *m* magnum *p*, pisiform *R* radius *rs*, radial sesamoid *s* scaphoid *td* trapezoid *tm* trapezium, *U* ulna *u* unciform I–V digits. (Courtesy Flower William Henry An Introduction to the Osteology of the Mammalia. By permission of The Macmillan Company publishers, New York.)

built on the same original fundamental structural heritage, the primitive hand. Animals of widely divergent classes may develop similar structures to live in similar ways. The following are some adaptations of the hand to the various environments

For Running From the elbow distalward the tendency is to reduction to a single bone in each segment, as in the horse, which has just the radius, a single metacarpal, and the three phalanges of his long finger, or to a pair, as in the ruminants, and to provision with durable evergrowing hoofs to withstand the wear The carnivora similarly are protected from wear with growing claws and five durable pads.

For Digging The mole, ant bear, and armadillo have long, strong claws and tremendous development of arms and shoulder girdle The mole has an extra projection from the radial side of the radius to broaden his spade. It is a radial sesamoid of one of the two tendons of the palmaris longus going to the first digit, the other of which goes to the fifth. The claws of the ant bear are so large and curved that he

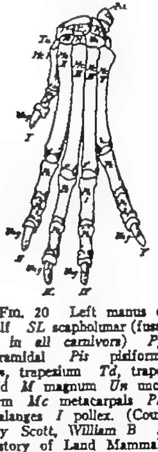


FIG. 20 Left manus of wolf *SL* scapholunar (fused as in all carnivora) *Py* pyramidal *Pis* pisiform *Tm*, trapezium *Td*, trapezoid *M* magnum *Un* unciform *Mc* metacarpals *Pk* phalanges *I* pollex. (Courtesy Scott, William B A History of Land Mammals in the Western Hemisphere. By permission of The Macmillan Company publishers, New York.)

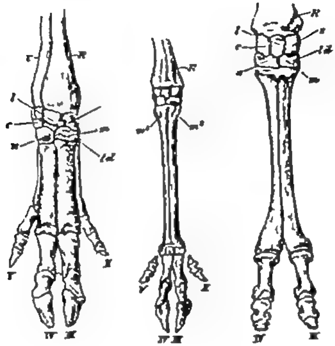
walks on the outer border of his hands with the digits and claws in flexion.

For Fighting The prehistoric reptile Iguanodon had the thumb developed into a formidable spike projecting at a right angle

from the hand Examples of modern weapons are the sharp erectile claws of the members of the cat tribe, the large claws of the bear, and the claw on the index finger of the cassowary

For Hanging The sloth moves slowly, hanging by his digits with the large claws, for hooking over the branches For this he does not use his small thumb

For Biped Progression The kangaroos and the jerboas, due to the great development of the hind legs, have forelimbs that are very small but are active for use as hands



A B C

FIG. 21 A. Bones of right forefoot of even toed animals.

A, pig B red deer C camel.

Metacarpi fused. First the thumb is lost, then the two marginal rays, leaving the third and fourth digits in the cloven hoof

U ulna *R* radius *c* cuneiform *l*, lunar *s* scaphoid *u* unciform *m* magnum *td* trapezoid. (Courtesy Flower William Henry An Introduction to the Osteology of the Mammalia. By permission of The Macmillan Company publishers, New York.)

but is helpless on the ground. With such existence his digits have been reduced to three in one species and two in another

For Adhering Sucker like pads have developed on the fingers of tree toads, geckos, and the Tarsus monkey for adhering to surfaces in climbing In the latter, the fingers are so long and slender that they can grip the limb from any direction

For Acrobatics. The gibbon is the champion swinging with his long arms from limb to limb, so he seems fairly to fly through the trees His fingers are long

For Swimming In swimming animals the front limbs are paddle-like, short, broad, and fairly thick for use in a dense medium, in contrast to those with large, thin, light expansions of their front limbs for flying in the lighter medium air The marine reptiles above mentioned, like the mammalian Cetacea (whales and dolphins) and the Sirenia (manatee) had their front extremities developed to short, broad fins, the pelvic girdle being absent or reduced to two rudimentary bones In Cetacea and Sirenia the arm bones are short and broad,

and there are five digits, but there are only four in the finned whales. The carpals in Cetacea are mosaic like and difficult to identify The manatee have two rows with three in each. The phalanges in Cetacea, as in no other mammal, are multiple, ranging from two in the thumb to 11 in the second digit. In whales the joints from the shoulder distally have lost their joint cavity and are fibrous. The arms and flippers of seals have well-differentiated bones much as in land animals, though short and well muscled. They are pentadactylate and without excess of phalanges Seal flippers unlike those of sea lions, are clawed the web extending beyond the claws.

The manus of the sea turtle contains the same bones and other structures as found in the land tortoise, but is converted into a long flipper for swimming. The pisiform is especially long for leverage of muscle action

In water animals less of the marine type, such as the sea otter, beaver, muskrat, and duckbill, the interdigital webs are well developed for swimming In the latter the webs extend far beyond the claws for swimming, but fold into the palm for use of the claws in walking and digging Birds like the penguin or auk have short thick wings for the denser medium and when submerged fly with them through the water just as other birds do in air

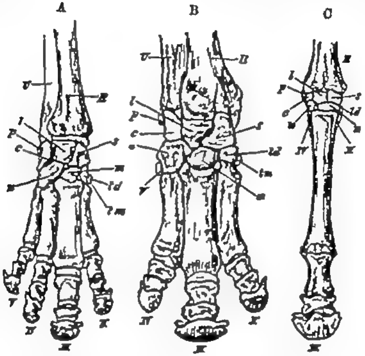


FIG. 21 B Bones of right forefoot of odd toed animals.

A, tapir B, rhinoceros C, horse.

Thumb is first lost, then the little finger and then the two marginal rays, so the horse walks on his long finger

c, cuneiform *l* lunar *s*, scaphoid *u*, unciform *m* magnum *td* trapezoid *tm*, trapezium. (Courtesy Flower William Henry An Introduction to the Osteology of the Mammalia By permission of The Macmillan Company, publishers, New York.)

For Flying Great development of interdigital webs is found in the flying frog but even greater still in the bat and the extinct Pterodactyl Bats have scapulae and clavicles like ours, but have long, light arm bones The metacarpals and phalanges are greatly elongated as three struts for

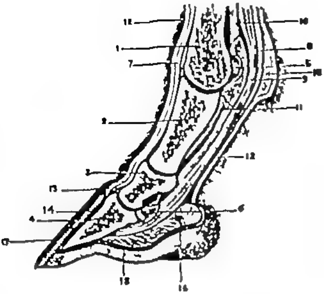


Fig. 22 A. Manus of horse. 1 metacarpal 2 proximal phalanx 3 middle phalanx 4 ungual phalanx 5 and 6 sesamoids 7 extensor tendon 8 flexor sublimis 9 flexor profundus 17, nail or hoof (Courtesy Flower William Henry and Richard Lydekker An Introduction to the Study of Mammals Living and Extinct, London, Adam and Charles Black, 1891)

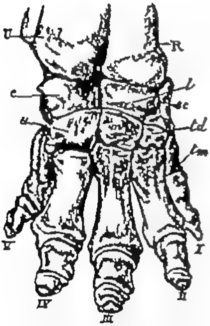


Fig. 22 B Right manus of elephant. *c* cuneiform *l* lunar *sc*, scaphoid *u* unciform *m* magnum *td* trapezoid *tm* trapezium. The ulna (*U*) is the larger forearm bone. (Courtesy Flower William Henry and Richard Lydekker An Introduction to the Study of Mammals Living and Extinct, London Adam and Charles Black, 1891)

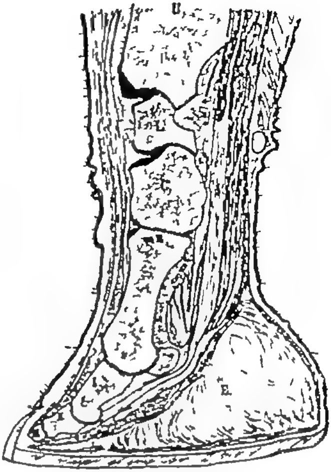


Fig 22 C. Elephas maximus. Lengthwise frozen section of front foot. U, ulna L, lunate C, capitatum m^{III} third metacarpal I II III, phalanges of third finger E, elastic pad. At the distal end of the third metacarpal is attached a sesamoid. Behind this lies the flexor muscle. (Note that the weight is borne on the digits and an elastic pad.) In front of the tendon is the extensor muscle. (Courtesy Weber Max Die Säugetiere, Vol. 2 Jena, Verlag von Gustav Fischer 1928)

wings, which are merely the two layers of skin of the webs The index and long fingers are close together forming the first strut, and the ring and little fingers the other two, the phalangeal formula being two—one—three—two—two From the tip of the little finger the web spans to the ankle. The short thumb projects free and has a claw with which he pulls himself along on the ground. The vampire bat walks high on his feet and thumbs

Pterodactyls, the prehistoric flying lizards, ranging in size from that of a sparrow to some with a 14-foot wingspread, had four fingers. The first three were free, but

the fourth was greatly prolonged as the single wing strut to hold the web which spanned from it to the foot. From the carpus there projected a thin bone toward the body which was at first thought to be

FIG. 23 Upper extremity of a Cape buffalo Shows vertical position of scapula in quadrupeds. As in most ungulates the weight is borne on the radius, the ulna with the exception of the olecranon process, being rudimentary and fused. The carpus is reduced. Metacarpals are fused to one and the third and fourth digits remain. (Courtesy Shipley A. F., and E. W MacBride Zoology—An Elementary Text book, Cambridge University Press, England. By permission of The Macmillan Company publishers, New York.)

the thumb If so, the wing would be held by the little finger It was suggested that the small bone from the carpus was not the thumb but only an ossified ligament, and that the first of the three fingers was really the thumb This was verified by finding that the phalangeal formula, starting with this first finger, was two—three—four—four—zero, thus conforming closely to that of reptiles and indicating that it was the ring and not the little finger that made the wing of the Pterodactyl

Other modifications for flight aside from those seen in birds are found in the broad web expansion between neck, hands, and feet in the flying squirrel, cabego, and flying phalanger Hands, however, are not necessary for flying, as the flying lizard and the flying snake of the Malays use spreading ribs for this purpose.

For Versatility and Handicraft. Here *man stands supreme.*

PRIMATE HAND

The hands of the various primates, including man, are very similar, and have changed the least compared with other mammals from the type of the primitive hand of early amphibians. Their minor variations are adaptations to their special activities.

Primates Primates range from the lowest types, the Lemuridae, through the monkeys (arboreal in habit, especially in the Western Hemisphere where many have prehensile tails) and up through the five types of anthropoid apes. Of these the gibbons, the orangoutang and the baboons are lower in the scale, and the chimpanzee and the gorilla the closest to man.

The gibbon is a wonderful acrobat, with greatest development of arms for swinging through trees, and when he stands his arms reach to the ground. He is but three feet high, but has an armspread of five and one-half feet. The orangoutang is a large, heavy, arboreal dweller His arms reach to his feet and spread seven and one-half feet. The baboon runs in packs on the ground, but is able to climb The largest ape, the gorilla, is too heavy for much climbing His hands reach to the mid tibia. He is gross in muscle and frame like Neanderthal man or a modern man with acromegaly, and is considered to be nearest to man. The chimpanzee is high mentally and is of a lighter build and more agile both on the

ground and in trees His hands reach to below the knees, while those of man, who has the longest legs, reach only to the mid third of the thigh

Thumb Of all mammals only the pri mates have opposable thumbs In other mammals the thumb is either absent, rudi mentary, or is like the other digits In the smallest and least opposable in arboreal forms, and even absent in some (as the spider monkey, whose need is supplied by the prehensile tail) Thumbs are much better developed in those that dwell on the ground In the howling monkey the cleft in the hand is between the second and third digits, and in the potto the index is a mere

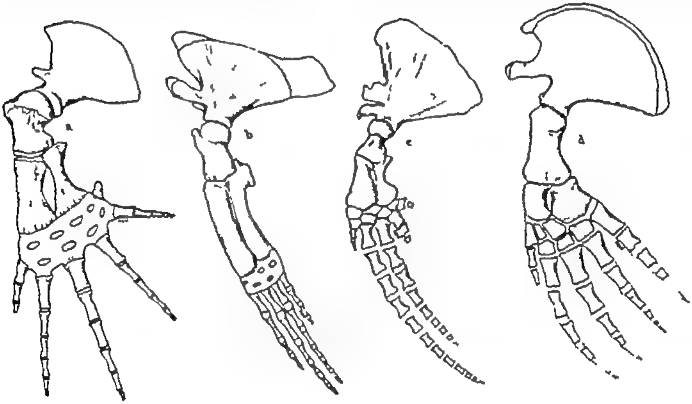


FIG. 24 Left pectoral limbs of mammals that reverted to sea life cataceous. Arm bones are shortened. Joints are without spaces, phalanges are multiple, but of not over five rays. a, Eubalaena Balaena or right whale, b Sibbaldus blue whale or rorqual c, Globiocephala pilot whale or black fish d Platanista fresh water dolphin River Ganges. (From Howell's Aquatic Mammals. Courtesy of Charles C Thomas, Publisher)

feet of birds the hallux opposes the other toes, and in owls the fourth digit can be placed either with or opposite the other toes Cuckoos, kingfishes, and woodpeckers have two pairs of opposable toes. Hands of rodents are nimble, most are thumbless and grip with their fingers against a pad in the palm.

Strangely, the lowest primates, the slow moving limb clingers, the Lemuridae, have the largest and most opposable thumbs, reaching the greatest development in the slow loris, in which the thumb can be spread to a right angle from the palm Of the later monkeys and apes, the thumb is stub, thus furnishing a wide cleft for the thumb

In man, the thumb shows the greatest specialization and development in strength, opposition, and size. Next in order come the great apes, the gorilla, baboon, and chimpanzee. Of apes, the thumb of the orangoutang is shortest, the distal phalanx often being absent. Though the gibbon does not use his thumb in his acrobatics, he can oppose it for holding objects. As in the orangoutang, it is deeply cleft and narrow, showing weak muscle control.

The pollical index, or percentage of length of thumb to that of the long finger,

chimpanzee its palmar aponeurosis, just beyond the center of the hand, forms the flexor tunnels and sends no slips to the fingers

FIG. 28 Hand of young Rhesus monkey Epiphysis arrangement of thumb and fingers is as in man. The os centrale shows as a distal portion of the scaphoid (bipartite) Sesamoids are multiple. (Courtesy Hartman, Carl G., and William L. Straus Jr The Anatomy of the Rhesus Monkey Baltimore, The Williams and Wilkins Company 1933.)

FLEXOR DIGITORUM SUBLIMIS This is fused with the profundus in lemurs and here a flexor digitorum brevis is still present. In baboons the sublimis has only one muscle belly, but in the chimpanzee the bellies are separate for each finger In the latter, the split of the sublimis tendon is proximal to the *metacarpal head*, so all three tendons bear separately on the bone. The origin in primates is always largely from the humeral condyle.

FLEXOR DIGITORUM PROFUNDUS. In the gibbons the muscle is split longitudinally for the third interdigital cleft and in other apes for the second. In Rhesus it is split on the third ray, both sides pulling on this finger In most primates the muscle has five tendons, the flexor muscle of the thumb as in other mammals not being differentiated.

FLEXOR POLLICIS LONGUS. Man alone has enough differentiation to have a strong flexor of the thumb, separate from the common profundus muscle. In the gibbon, also, the muscle is separate but is weak. It is usually absent in the gorilla. In the chimpanzee and orangoutang there is only a narrow tendon from the distal phalanx of the thumb to the transverse carpal ligament, though in some it reaches the flexor profundus belly to the index finger It acts as a tenodesis, flexing the thumb automatically on tensing the abductor pollicis longus In the Tarsus the muscle is almost separate and in the baboon there is a common profundus.

EXTENSOR PROPRIUS INDICIS AND MINIMI DIGITI. In most mammals and lower primates and the gibbon there is a tendon to each digit from this deeper second layer of extensor muscles. In other apes there may be, in addition to the tendon to the index and little fingers, an adjoining one to the long or ring.

ABDUCTOR POLLICIS LONGUS. In most primates this muscle has two tendons, one to the metacarpal and the other to the trapezius (chimpanzee, gorilla, gibbon, but only one in the orangoutang), thus explaining this aberrant tendon in man.

EXTENSOR POLLICIS BREVIS This tendon on the ulnar side of the abductor pollicis is found only in man and some gorillas

The muscles that move the wrist, the extensor digitorum communis and extensor pollicis longus, are as in man

Nerves The nerves are largely standard from amphibians to man, being exceptionally constant to the muscles supplied by them In Amphibia the interosseous branch was the main median nerve and ulnar communicated with the median the forearm Later the superficial bra became the main median nerve and ulnar increased in size to supply the ha Throughout primates the arm and h nerves are practically the same

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2

The Normal Hand

Next to the brain the hand is the greatest asset to man, and to it is due the development of man's handiwork. It is also an organ of expression and a special sense organ for stereognosis. Our brains are crowded with memories and conceptions of objects and actions which have been built up and developed by sensation and use of our hands. Through hands we have acquired by feeling much of our knowledge of shapes and textures of the objects of this world. Our very thoughts are linked with the sensations and actions of our hands, not only in our fundamental activities concerning shelter, food, combat, and perpetuation, but in constructing, such as building, drawing, sculpturing, and even thinking.

The motive of this chapter is that we must know the normal to recognize the pathologic. If we have at the start a clear, crisp conception of the morphology and function of the hand in all its details, defects or deviations from the normal become at once apparent. In plastic work, if we first imagine the normal shape the deformity stands out conspicuously. So it is with the functions of all the tissues of the hand. We must know the normal in order to diagnose and reconstruct.

SKIN AND CREASES

The skin of the volar surface of the palm and fingers is tough and thick to stand hard wear, and is upholstered beneath by a tough buffer of fat. It is not very pliable and does not lend itself well to plastic maneuvers. It covers, in general, a concave surface which is interdigitated. This surface becomes more concave on making a fist. Therefore, this tough unyielding skin must have a system of creases to allow for this motion, much like the joints of an arthropod or a suit of armor.

The skin covering the dorsum of the hand is thin, soft, and yielding, and so is its subcutaneous tissue. It covers, in the main, a convex surface which becomes more convex on making a fist. Therefore, the dorsal skin instead of having the deep organized creases of the volar skin must be flexible to reach from wrist to fingernails on making a fist. Accordingly, in the extended hand it is everywhere lined with minute wrinkles, all of which are placed at a right angle to the line of pull to allow for the stretching on flexion. There are special redundancies over each of the finger joints most of which show transverse wrinkles, but those wrinkles over the middle finger joints are elliptical in pattern so as to fit the spherical shape these extra mobile joints assume on full flexion. The wrinkles over the dorsum of the wrist are transverse for dorsiflexion and those on the dorsum opposite the thenar eminence are longitudinal to allow for stretching, such as oc

curs when the thumb touches the little finger The skin on the dorsum bears hair with the exception of the distal one or two segments of the digits, but all of the volar skin is free from hair or pigment.

On the volar surface of a finger two cross creases are seen opposite the middle joint, but there is only one crease at the distal joint of the fingers and thumb Thus, there are two creases in the front of the wrist for the radiocarpal joint, two across

FIG. 29 Showing how with the finger flexed the fat pads form wedges and the creases a cross. Volar creases do not pass the mid lateral line or line for incision.

the palm (called together the distal palmar crease) for movement of the proximal finger joints, and two in the thumb opposite its proximal joint. Of the composite distal crease in the palm, the distal of these creases runs from the second cleft to the ulnar border of the hand and is for use of the long, ring, and little fingers against the thumb The other more proximal commences with the thenar crease at the radial border of the palm and travels toward the ulnar border It is for action of the index, long, and ring fingers against the thumb In monkeys and some humans the distal crease extends completely across the palm, not differentiating for separate movement between the ulnar and radial sides of the hand.

The thenar crease allows for adduction and opposition of the thumb The thumb forms a cone extending radially from the side of the hand, but also can form a cone extending forward from the hand, or it may parallel the index finger For forward motion the thenar eminence shows wrinkles longitudinal with the hand which circle around to the dorsum to allow for extension of the thumb The webs between the digits are all on the volar plane instead of the dorsum, which makes for better grasping and better swimming The palm is thus broader and longer than is the dorsum. The web in the first cleft when the thumb is extended runs longitudinally from the thumb to the radial border of the hand. As the thumb travels backward this fold become oblique, and as it travels forward the opposite obliquity is shown. As the thumb approaches the index finger the crease becomes transverse.

The distal border of the palm is marked not by a joint crease but by a fold or plica which reaches almost to opposite the centers of the proximal phalanges. This convex transverse fold is greatest on making a fist, and the palm is then 1½ inches shorter than when the hand is straightened. A similar lateral fold to allow for the changing width of the palm is seen on the radial side next to the thumb From hard work these folds become thick with calluses.

On full flexion of a finger the skin of each of the finger segments becomes pleated crosswise into triangular shapes as seen from the side, with the point of each, together with the distal palmar fold, touching the other at a central point. The creases then form the shape of a cross, the distal finger crease then being continuous with the proximal and the middle finger crease continuous with the palm Each of the three volar creases crossing a finger attaches directly to the sheath of the flexor tendon without the intervention of subcutaneous fat, thus dividing the volar subcutaneous fat of the finger into three distinct pads. Puncture wounds through these creases enter directly into the tendon sheath and the creases also act as barriers to limit subcutaneous infections.

The nails back up the pulps broadly, so as to give firmness to this most useful surface of the fingers in pinching and holding objects The volar skin over the whole hand, and especially over the distal segment of each digit, is covered with rugae used in finger printing Each of these is a ridge of epidermis dotted with sweat gland openings or pores and overlying two rows of papillae of the corium The object of rugae on our specialized tactile surface is apparently for better and crisper stereognostic perception, just as the cross hatching in picture reproduction gives better contrast. The most sensitive part of the finger pulp is at the central loop or whorl

MOVEMENTS OF UPPER EXTREMITY

From shoulder to hand there is a series of joints which give to the hand, compared with the manus of lower mammals, most unusual versatility of motion The palm can be placed parallel to cover any part of the body, with the exception of an area in the dorsal region between the shoulder blades, and can pull to or push away from any part of the body By movements of the shoulder, elbow, and wrist it can do this anywhere from a position next to the body to a distance of arm's length. With the arm extended as the radius, each hand describes arcs throughout more than a hemisphere, and by bending the elbow and wrist they reach back of this through considerably more than the hemisphere. By the shoulder, elbow, and wrist joints, the hand, with arm extended, can rotate on its long axis through almost a complete circle, palm up to palm up The shoulder, being a ball and-socket joint, has a large range of motion, angulating and rotating widely

The two radio-ulnar joints furnish pronation and supination and the wrist is a universal joint, all aiding in the rotary motion of the hand.

The elbow hinges in one plane until in its last one third of extension it angulates outward to form the carrying angle

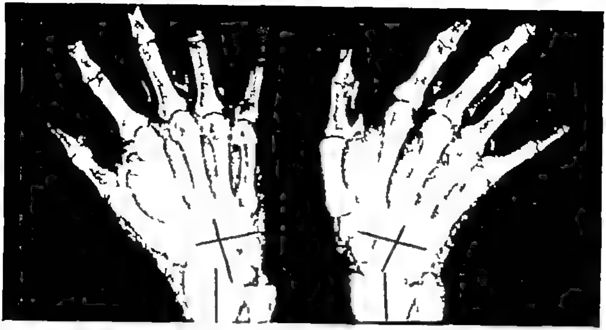
Pronation and supination with the elbow fixed at the side is through 180° measured at the hand, but is from only 120 to 150° measured at the wrist. With the forearm resting along its ulnar border on a table and the hand in pronation with the palm against the table, the hand can be then rolled over its ulnar border until its dorsum is next the table, and the position is that of supination In changing from the palm down to the palm up position, the ulna is fixed and has its styloid process next the table The radius at the wrist rolls around over the head of the ulna, so that its lower end is first to the inner side of the ulna and then to the outer side, the radius alone executing the movement on the ulna.

LOWER RADIO-ULNAR JOINT

Each radio-ulnar joint has the same degree of rotary motion. At the upper joint

FIG. 30 End view of radius and ulna to show their relations in pronation and supination. The ulna does not turn. Its styloid is always posterior The radius, with the articular disk, performs an arc of less than 180° about the center marked O

there is a true swivel with an orbicular ligament, but not so at the lower joint. At the lower joint, the radius rotates about 150° around the fixed ulna, which does not rotate The hand rotates 180° The head of the ulna has an articular facet opposite the styloid process comprising only two-thirds of the circumference of the head. For this joint there are only three ligaments One is the strong pivot ligament from the styloid process to the triquetrum,



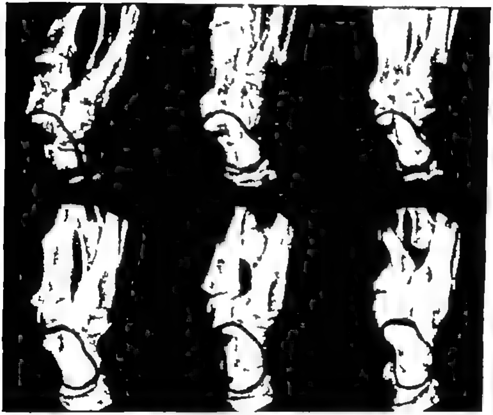


FIG. 32 (*Top*) Lateral movement of the wrist joint occurs in equal amount in the radiocarpal and midcarpal joints.

Lines are drawn longitudinally through centers of radius and capitate and a cross line extends between the distal points of navicular and triquetrum to measure the angles of movement in the above two joints. Capitate moves with hand on the proximal carpal row including the greater multangular and thumb ray Because of this the thumb reaches farther down the index finger in radial flexion than in ulnar flexion.

In radiocarpal joint is shown movement of proximal carpal row on radius and ulna.

FIG. 33 (*Bottom*) Lateral movements of the wrist are accomplished by movement within the carpus. The navicular angulates forward in radial flexion of the wrist to avoid the radiostyloid and almost parallels the wrist in ulnar flexion. The capitate with the hand moves in the opposite direction.

The six lateral views were taken serially of graded positions of the wrist from in strong radial flexion (*top left*) to that of strong ulnar flexion (*lower right*)

ead of passing between the navicular greater multangular bones The thumb then moves with the proximal carpal and the hand has lateral motion on e bones as a unit Therefore, in radial on of the wrist, the tip of the thumb hes to the middle volar crease of the x finger, but in ulnar flexion it lacks half inch of so doing This compensates the gliding of the triquetrum on the ate Therefore, unlike the conventional tomic usage of proximal and distal rows arpal bones, clinically the greater mul gular bone should be considered in the ximal carpal row

avicular in Lateral Movements. Tilt of the navicular accompanies lateral ements of the wrist As the wrist radio- es the navicular angulates volarward to id impinging on the point of the radio- loid *in the movement of the radiocarpal* it In Figs 33 to 34 the six roentgen s of lateral views of the wrist show con utive positions of carpus from ulnar to ial flexion

Commencing in ulnar flexion of the wrist en the navicular is angulated volarward from the capitate, this bone gradually ulates more as radial flexion is reached il it attains an angle volarward of 60° the same time the capitate angulates 35° salward on the lunate In ulnar flexion lunate shows a tipping dorsalward, and the wrist radioflexes it angulates until en the wrist is fully radioflexed it is in aight alignment with the radius In rt, the lunate moves somewhat with the vicular to form with the capitate the ove conspicuous angle when the wrist is radial flexion This backward angula n of the capitate on the lunate accounts the dorsal deviation of the plane of otion of the hand in radial flexion, the nd and capitate angulating to behind d the navicular to in front of the radio- yloid The mechanism of this is apparent palpating, while in action, the two radial xors of the wrist, namely, the extensor carpi radialis longus and the abductor pol licis longus, which cause the divergence

Muscle Action of Wrist. Wrist move ments are mainly activated by the six fore arm muscles, which attach to the bases of the metacarpals abductor pollicis longus to first, flexor and extensor carpi to second and third, and ulnari to pisiform and fifth.

The carpal bones move largely passively, though there is some controlled differential

FIG. 34 Navicular (outlined) inclines forward when the thumb is opposed.
(*Left*) Thumb is in opposition and wrist is slightly dorsiflexed.
(*Right*) Thumb is at the side of the hand and wrist is straight.

action between the two rows, in that the proximal row does receive some muscle pull from the flexor ulnaris on the pisiform and from the abductor pollicis longus by an occasional slip to the navicular Also, this *latter muscle pulls* on the thumb ray, which can be considered, as shown above, as a prolongation of the proximal carpal row

MOVEMENTS OF HAND

The shape of the hand ranges from flat or slightly concave dorsally to that of a ball fist. The digits spread widely as the hand opens and converge at their tips as it closes. The hand can pick up any size object from a tiny seed using the fingernails, to a nut using the converging fingertips, or to an

8 inch ball using the whole hand. When two hands are used a much larger object can be grasped.

Arches of Hand. There are two arches of the hand, one at the metacarpal heads and the other in the distal row of the carpus The thenar and hypothenar muscles with the exception of the two abductors maintain and increase these two arches. They pull the outside rays toward the front of the carpus. The palmaris

Fig 35 Showing carpal and metacarpal arches. As the hand flexes the tips of the digits are aligned in the same plane for grasping until near the palm.

longus aids to a slight extent as it pulls on the center of the transverse carpal ligament. Depending on these arches are strength on pressing with the palm, the motions of opposition of the thumb and also of the little finger, the ability to grasp a ball, and the convergence of the digits on flexion. When the hand is flat the carpus is broader than long, but when arched, it is longer than broad.

The hand in partial flexion forms a semisphere, convex on the dorsal aspect and concave on the palmar As a fist is made the curves of the arches increase. Due to the tipping of these axes of the proximal finger joints on curving the metacarpal arch, the digits spread on extension to grasp more and bigger objects and converge on flexion like a hawk's talons. Therefore, the spreading of the fingers by the long extensor tendons may be misinterpreted as lateral motion of the fingers by the intrinsic muscles When, however, the metacarpal arch is held straight, as by grasping a rod, the axes of the proximal finger joints are maintained in a straight line instead of being tipped, so the fully flexed fingers are parallel and do not converge. The rod straightens out the arch.

Normally, on flexion each finger points toward the tubercle of the navicular If traction is applied to them it should be in this direction When each finger is flexed in series each touches a spot at the base of the thenar eminence When flexed together, they touch the palm along a line from the base of the thumb to the hypothenar eminence and have very little lateral play

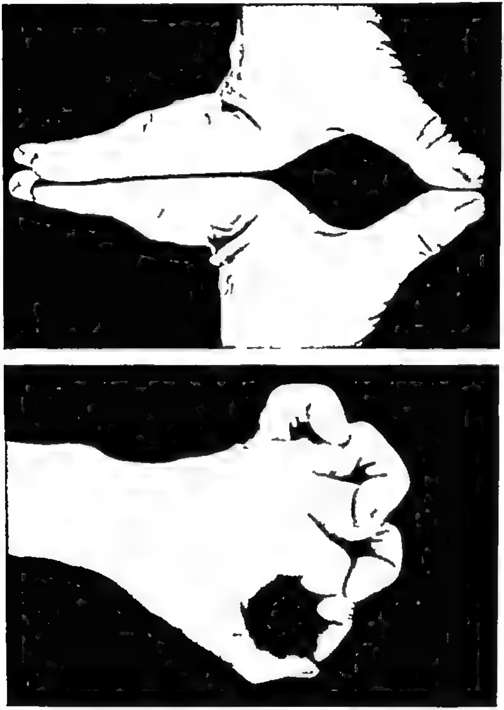
The extended fingers are unequal in length, the long finger being the longest. In semiflexion, however, their tips form a straight line. In grasping various sized balls the tips of all five digits are aligned in the same planes. Thus, if the open hand is laid on a flat surface and the hand be gradually flexed to a fist, the tips of all five digits will remain aligned on this plane until flexion is two-thirds completed. On complete flexion the inequality reappears the tip of the long finger being still in the lead and the finger tips fitting into the arch in the palm This phenomenon is adapted for grasping any size of ball, stone, fruit, or nut, as practiced since early biped days. Due to the metacarpal arch, the ring finger in many is longer than the long, when they are held straight forward from the palm

Mechanics of Finger Motions. In a flexed digit the prominence of each and every joint is the end of the proximal bone of that joint. In other words, the joints of the digits are sliding joints like the knee, the phalanx in flexion sliding to a position end to volar surface with the bone proximal to it. Thus, in flexion the flexion creases in palm and digits are opposite the proximal part of the heads of the proximal bones and the proximal borders of the distal bones of each joint. The proximal

finger joints flex 90 to 100°, the middle 110 to 130°, the distal 45 to 90°

All joints of the digits show some lateral mobility when extended, but none when flexed. This makes for a firmer grasp of objects as no side motion is allowed The mechanism of this is greatest in the prox imal finger joint and is due to two factors, the shape of the ends of the metacarpals and the tightness of the collateral liga ments The ends of the metacarpals are quite narrow anteroposteriorly in their part that articulates when the fingers are in extension, but are broad and flat on their volar aspects to receive the flat ends of the proximal phalanges, so the fingers on full flexion are broadly and firmly braced The collateral ligaments are loose when the

A



B

Fig 36 (A and B) Limber or double jointed hands.
(A) Proximal joints overextend.
(B) Excessive rotation in finger joints.

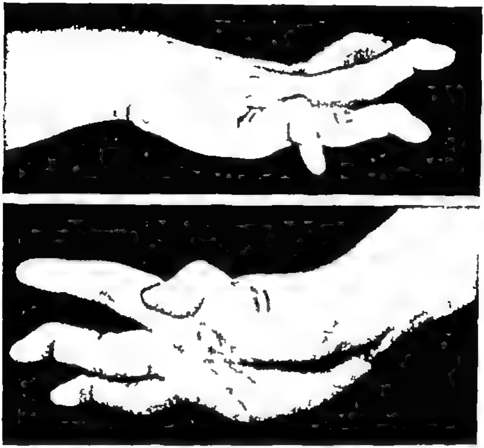
fingers are extended, but are taut in full flexion, the combination preventing all lateral motion in the latter position

This lateral motion in the proximal finger joint is present only when the fingers are extended. It is greatest in the two end fingers, little and index, amounting to 60 and 50° respectively, and less in the long and ring fingers amounting to 40 and 30° respectively

The four dorsal interossei abduct the fingers from the long finger, and the three volar ones adduct them to it. The lumbricales help on the side they happen to be, which is almost always radial.

Each digit when extended has some motion of circumduction, due to the coordinated action of the various muscles that work upon it. All fingers can be flexed until they touch their bases. Their tips are then in a line. Then as their proximal joints continue the flexion the finger tips touch the distal crease in the palm the tips fitting the curve in the palm The final clenching into the distal crease is done by the flexor sublimis muscles. Some "double-jointed" people can flex their distal finger joints alone. They do this by first stabilizing their double-jointed middle finger joints in hyperextension The extensor tendon usually shows in these cases as two bands instead of one, as its two lateral branches which span the middle joint are made prominent by the hyperextension.

C



D

FIG 36 (C and D) By throwing the middle finger joint into hyperextension by tensing the long extensor the distal joint can be flexed alone.

The tendons of the flexor digitorum profundus pull from a common muscle and also interdigitate in the base of the palm Therefore, if any finger is held in extension (least so with the index) the adjoining fingers cannot be fully flexed voluntarily, but can be passively

The tendons of the extensor digitorum

communis pull from a common muscle and interdigitate in the dorsum of the hand, and are also joined by oblique bands near the knuckles. Therefore, if any finger is held in full flexion the adjoining fingers cannot be fully extended voluntarily, but can be passively.

Because of the above, when one tendon is held in an amputation stump in the scar, motions of the other fingers will be limited.

Carpal Region. When weight is borne on the palm, strength is furnished by the carpal arches and by the arch of the radius. The latter bone is arched volarward, both for strength in palmar pressure and for accommodation of the muscle bellies. The distal articular surface of the radius is tipped volarward for receiving this force. Pressure on the carpus of the palm is withstood by four bony prominences: the tuberosity of the navicular and oblique ridge of the greater multangular bone on the radial side, and on the ulnar side the pisiform and hook of the hamate. These four bony prominences act as hooks to make the flexor tendons of the digits converge as they glide through the narrow channel of the wrist, and also serve for attachments of the transverse carpal ligament and to protect the nerves, vessels, and tendons as they pass through the wrist. The two projections on the ulnar side are more prominent, being more necessary to hold in the tendons as ulnar flexion is greater than radial flexion. The channel between these prominent bones is oblique, so that when the wrist is in its natural position of ulnar flexion the channel is in line with the forearm.

Thumb Motions. The thumb stands out as a cone at either the side of the hand or in front of the hand. When fully extended it can circumduct, describing an irregular circle, starting with its tip at the ulnar border of the hand at the base of the little finger, traveling with its tip across the volar surfaces of the fingers to the middle crease of the index finger and then passing in a curve at first slightly posterior to the plane of the palm, and then around well forward in opposition to its starting point at the ulnar border of the palm. Tip to tip with the index finger it forms a round O, and with the little finger an ellipse. In flexion and adduction it reaches the ulnar border of the palm at the base of the little finger.

FIG. 37. Carpal arch. The nerves and tendons are protected by the carpal ligament spanning over the four prominences of the carpus. On the radial side is the tuberosity of the scaphoid and oblique ridge of the greater multangular. On the ulnar side are the deeper pisiform and hook of the hamate. These four hooks hold the tendons in the canal and especially on the ulnar side in ulnar flexion. The force of a fall on the carpus is taken on these four projections.

In extension it reaches to an inch behind the plane of the dorsum of the hand, and it spreads to about a right angle with the radial border of the hand. Its distal joint in many cases hyperextends, in double-jointed people its proximal joint.

In opposition its tip reaches a position three inches in front of the base of the long finger. When the thumb is at the side of the hand the nail is at a right angle to the palm. As the thumb circumscribes forward in the motion of opposition rotation commences after the first third of this motion,

principally at the metacarpophalangeal joint though somewhat in all joints, until at the maximum of opposition the nail of the thumb is parallel to the palm and the pulp of the thumb faces those of the fingers and motion of the thumb and fingers is exactly toward and from each other The *greater multangulum moves with the thumb* on the rounded distal end of the navicular

FIG. 38. Vertical roentgenogram of the wrist demonstrating the bones of the carpus, which form the borders of the carpal canal and the relationship between the ulnar nerve and the hook of the hamate or unciform bone and the pisiform bone. The ulnar nerve (indicated by white portion of illustration) crosses over the tip of the hook of the hamate. (Courtesy Hart, Vernon L. Jour Bone and Joint Surg., 23 948, 1941)

which also angulates forward in opposition Most of the angular motion takes place at the carpometacarpal joint and most of the rotary motion at the metacarpophalangeal joint, though all the thumb joints participate to some degree in each.

The thumb of the extended hand reaches to almost the middle crease in the index finger It exceeds it when the wrist is radioflexed and fails it by one-half inch when the wrist is ulnar flexed. As the distal joint of the thumb flexes it also angulates slightly radialward to grasp a larger object. Flexion of the thumb and that of the index finger are associated together from habit, and moving one generally results in a movement of the other The area of the hand which can be touched by the thumb is the distal part of the palm, the volar and radial surfaces of the length of each of the fingers, the radial half of the dorsum of all of the fingers and the ulnar half of the index and long fingers. With its long extensor tendon alone the thumb can squeeze against the radial border of the hand The long abductor muscle is necessary to hold the thenar eminence *at the side of the hand. Without it the thenar* eminence rides forward and the thumb is useless The grip with the thumb against the index and long fingers is stronger than against the ring and little fingers, as the adductors of the thumb attach to the metacarpal of the long finger

MECHANICS OF MUSCLE AND TENDON ACTION

Coordination. Rarely if ever is a motion carried out by one muscle and tendon Motions are the result of coordination by a number of muscles and tendons, some of them causing most of the motion, others deviating the direction of the motion and still others holding back the motion to make it slow and controlled. Besides those muscles acting on the moving joints themselves, many muscles proximal to these to as far proximal as the juncture of the limb and the trunk are acting in a stabilizing manner to hold the limb in position so the distal joints may move.

Stabilization and Angulatory Action. This stabilizing action occurs in two ways. One is by the tone and also voluntary contraction of the muscles pulling in the line of the limb, so as to *hold* the bones firmly together at the joints. The other, which is the usual interpretation, is by muscles holding the proximal joints firmly in flexion or extension so that the distal joints can be moved. As a concrete example of the latter, when we make a fist the extensors of the wrist must first stabilize the wrist in firm dorsiflexion to allow the digits

to grip Otherwise the wrist would go into flexion and the force of the grip would be lost. Hence, we strain the origin of the extensors of the wrist (tennis elbow) in gripping Another example is in making a firm O between the thumb and index finger For this the long abductor muscle of the part lateral motion to the fingers, nor can they extend the distal two finger joints Conversely, unless the lumbricales and interossei stabilize the proximal finger joint in strong flexion, the long extensor muscle is unable to extend the distal two joints

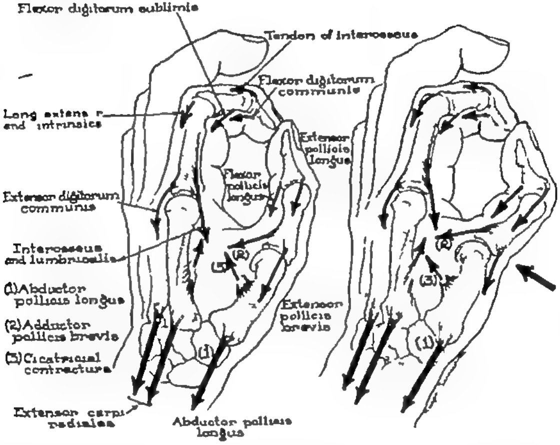


FIG. 39 Mechanics of pinching between thumb and index finger forming a good arch of the thumb

(*Left*) Stabilization by each muscle in forming the arches of the pinch.

(*Right*) The metacarpophalangeal joint drops from any of the following causes (1) Lack of stabilization in extension of carpometacarpal joint by abductor pollicis longus, (2) lack of stabilization in flexion of metacarpophalangeal joint from loss of adductor brevis in ulnar palsy (3) flexion contracture between first two metacarpals.

thumb must stabilize the carpometacarpal joint in extension and the short adductor and flexor of the thumb must stabilize the metacarpophalangeal joint in flexion. If either of these stabilization factors is missing the arch of the thumb will be destroyed as the metacarpophalangeal joint will drop into extension, resulting in weakness of pinch. In the fingers unless their proximal joints are stabilized in extension by the long extensor tendons, the lumbricales and interosseus muscles will not be able to im

As we reach out to pinch with the thumb and index finger, or to make a fist, many muscles from trunk to digits spring into action to hold out the arm for the hand to act. Stabilizing the shoulder are the scapulothoracic, humerothoracic and scapulohumeral muscles, and acting on the elbow are the flexors, extensors, pronators and supinators. The whole series of co-ordinating, stabilizing muscles from trunk to hand are activated when the arm places the hand for action

Angles of Approach and Leverage. In order that a tendon may move a joint there must be some length of lever arm between the insertion of the tendon and the center of motion of the joint and the angle of approach or pull, that is, the angle between the line of pull of the tendon and the line of the part of the limb to be moved must be appreciable, such as 20 or 30° The greater the angle the more flexion

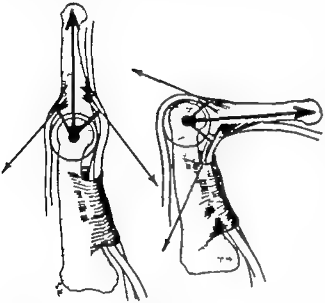


FIG 40 Mechanics of a finger joint showing the circle and center of movement, and the angles of approach of the tendons in both extension and flexion.

effect the tendon will have, and conversely, the less the angle the more will be the stabilizing effect in the first sense and the less the effect on flexion. Mathematically, the force of these two tendon actions, flexion and stabilization, is proportional to sine and cosine of the angle of approach. As the joint flexes the angle of approach increases, so the muscle gains in rotary and loses in stabilizing effect. The latter is here used in the sense of holding the bones together When the angle of pull is at a right angle to the lever arm, the whole force is of flexion and none of stabilization Some examples of this are short adductor of thumb, flexors of finger joints, biceps, triceps, pectoral and latissimus dorsi when the joints are in semiflexion The lumbricalis starts its angle of approach at 35° which is large for this in the hand. In quadripeds and higher apes the pisiform is the most conspicuous carpal in the wrist because it stands far volarward as a long lever This allows the flexor ulnaris to pull at a right angle and with long leverage for better strength in locomotion. For the purpose of increasing this angle of approach of the tendon to the bone, there is a definite expansion of the distal end of each long bone in the hand, including the radius, metacarpals, and phalanges. This gives a wider angle of approach for both the extensors and the flexors The four bony prominences in the volar aspect of the carpus which cause the flexor tendons to the various digits to converge at the wrist increase the angle of approach of these tendons to the lateral rays. The loop which the flexor sublimis tendon makes as it straddles the flexor profundus tendon regulates the angle of approach of the latter on the middle phalanx. Increased lever action is afforded by the prominent tendon insertions on the dorsum of the bases of the metacarpals and phalanges.

In a finger the flexor tendons pursue an undulating course in order to increase this angle of approach At each joint they round far volarward over the projecting proximal bone, articular cartilage, and capsule, and as they cross through the interspaces opposite the shafts of the metacarpals and phalanges the tendons bow dorsalward, being held so by the three pulleys or ligamentous annular bands. The proximal two of these bands are like one, being separated by only a three-eighth inch length of thinner sheath at the joint, and together are from one to 1⅛ inches long They are opposite the heads of the metacarpals and the proximal halves of the proximal phalanges. Considering that the head of each bone which forms the proximal half of a finger joint projects well volarward, it is seen that the undulating course gives quite an efficient angle of approach for the long flexor tendons. Similarly, the extensor tendons of the fingers have a good angle of approach when the finger joints are in

flexion When the joints, however, are near extension the projection backward on the distal member for attachment of the tendon furnishes a lesser angle of approach and consequently less force of extension

The lateral expansion of the bases of the proximal phalanges for interosseous attachment facilitates lateral motion of the fingers

The annular bands or pulleys on the dorsum and volar aspects of the wrist and in the fingers prevent the tendons from bowing across the joints on strong flexion Loss of these annular bends destroys the mechanics and efficiency of tendon action, and also places too much slack in the tendon for it fully to flex the joints in its limited excursion

Muscle Balance in Hand — POSITION OF FUNCTION The hand at rest assumes a certain position This is largely the mid position of the range of motion of each and every joint, including wrist and rotation of the forearm The muscles are all nicely balanced so that at their normal tone when at rest the position called position of function is assumed like the symbol on the title page of this book The forearm is halfway between pronation and supination The wrist is in about 20° of dorsiflexion and 10° of ulnar flexion. The fingers are slightly flexed in each of their joints, the index being flexed least and the little finger most The thumb is forward from the hand in partial opposition and its joints are also partially flexed

This muscle balance which is necessary for normal position and function of the hand is between the three sets long extensors, long flexors, and the intrinsic muscles in the hand If this nice balance be upset by the loss of any one of these, the hand assumes a position of deformity and is handicapped in function In the functionating or balanced position all these muscles are mechanically right for their best action

In this position the hand fits around an elongated fusiform object 1¾ inches in diameter and at an angle of 45° with the forearm It is probably an ancestral position ready for grasping limbs, weapons, or other creatures

The cleft between the thumb and the hand is directly in the line of the forearm for reaching forward for grasping This is seen in the anteroposterior view of the open hand due to ulnar flexion of the wrist, and also in the lateral view because of dorsiflexion of the wrist and opposition of the

FIG. 41 The position of function.

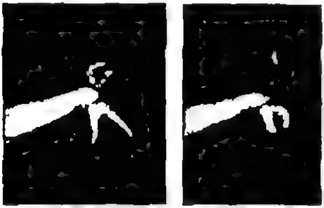
thumb Dorsiflexion of the wrist also presents the tough palm properly for shoving away or for bearing our weight on our hands Our grip is slightly stronger when the wrist is moderately ulnar flexed, as then our first four or main gripping digits are in alignment for the tendons to pull straight through the narrow wrist channel, and this oblique channel is then parallel with the tendons.

COMPOSITE ACTION OF MUSCLES Muscles are arranged about the joints, not only in pairs for antagonistic motions in the two more or less opposite directions, but are arranged somewhat around the joints so that by a coordination of their actions the movement may be in any plane and even in circumduction, such as in the proximal joints of the fingers and thumb and in the wrist joint. Joints within the digits move in one plane

About the wrist its extensors and flexors

are antagonistic, but only the extensor carpi radialis brevis acts in the true anteroposterior plane. The ulnaris muscles also ulnar flex and the long extensor and radial flexor of the wrist also radial flex. The extensors and flexors of the digits aid, too, in all these motions of the wrist.

Movements of the digits are from the *composite action of many muscles, varying* from seven to eight in the fingers to ten in the thumb



A B

FIG. 42 (A) A motion which feels natural as it is in accord with automatic movement.
(B) A motion which feels strained as it is counter to automatic movement.

The thumb is controlled by four long muscles and six short ones arranged about its circumference and supplied by three different nerves—radial, median, and ulnar —roughly for extension, flexion, and adduction, respectively *The long abductor and* the thenar muscles control the base of the thumb strongly for more distal action by the other three long muscles. The long extensor of the thumb is used to pinch with the thumb against the border of the hand, to draw it to a plane behind the hand, and to extend both of its distal two joints. The long abductor acts *against formal* antagonists as a strong stabilizer to keep the carpometacarpal joint in extension and the thenar eminence from being pulled forward in the palm Action of muscles controlling the fingers may be found in Chapter 10 (Intrinsic Muscles of the Hand)

Automatic Motions Movement of one joint in a limb has the automatic effect of moving the adjoining joints both proximal and distal to it, and especially when the same muscles span multiple joints This is seen particularly in the relationship of movements of the wrist and fingers When the wrist is dorsiflexed, the long flexor tendons become tense and *automatically* flex the digits, and when the wrist is volar flexed, the long extensor tendons similarly *extend the digits. If we attempt to dorsi* flex both the wrist and digits at the same time, or volar flex them at the same time, we feel in the tendons a certain strain, whereas their movements, when in accordance with the automatic combinations, are quite easy to execute and without strain.

These automatic movements are extensively utilized by paralytics with insufficient musculature for the digits Surgically the principle may be utilized in cases in which the long muscles to the digits have been lost but in which wrist motions are retained If the digital tendons are attached to the forearm bones, wrist motions will then move the digits

AMPLITUDE OF EXCURSION OF TENDONS

The various tendons, in moving the wrist and digits, each slide a certain distance to *execute the movement. This amplitude of* excursion of each tendon we measured in a fresh cadaver to determine it for each individual joint and also for the complete motion of flexion and extension as a whole when all of the joints are moved Our results are tabulated in the following tables. Each excursion of tendon was measured above the wrist, starting for the flexors with the wrist and digits in full dorsiflexion and starting for the extensors when the wrist and digits were *in full volar flexion. For each measurement* the joint indicated was the only joint moved. For each tendon the total excursion in moving all of the

EXCURSIONS OF TENDONS

	Extensor Proprius and Extensor Communis (in mm)	Flexor Profundus (in mm)	Flexor Sublimis (in mm)
Index Finger			
Distal joint	0	5	
Middle joint	2	20	16
Proximal joint.	15	15	16
Wrist joint	38	16	16
Full flexion of all joints	54	50	53
Long Finger			
Distal joint	0	5	
Middle joint	3	17	16
Proximal joint.	16	23	26
Wrist joint	41	38	46
Full flexion of all joints	55	85	88
Ring Finger			
Distal joint	0	5	
Middle joint	3	12	11
Proximal joint.	11	15	21
Wrist joint	39	45	40
Full flexion of all joints	55	76	65
Little Finger			
Distal joint	0	3 5	
Middle joint	2	11	8
Proximal joint.	12	15	17
Wrist joint	20	45	40
Full flexion of all joints	35	70	60

Thumb	Extensor Pollicis Longus (in mm)	Extensor Pollicis Brevis (in mm)	Abductor Pollicis (in mm)	Long Flexor (in mm)
Distal joint	8			12
Proximal joint	7	9		20
Carpometacarpal joint	6	7	5	8
Wrist joint.	33	14		[illegible]
Totals.	58	28	28	52

Measurements were taken starting with the wrist in the straight position

Tendons	Palmar Flexion (in mm.)	Dorsi-Flexion (in mm.)	Total A.P Motion (in mm.)	Radial Flexion (in mm)	Ulnar Flexion (in mm)	Total Lateral Motion (in mm.)
Extensor carpi radialis longus	16	21	37	8	16	24
Extensor carpi radialis brevis	16	21	37	4	12	16
Extensor carpi ulnaris	14	4	18	3	22	25
Flexor carpi radialis	20	20	40	2	4	6
Flexor carpi ulnaris	13	20	33	6	9	15
			Average 33 mm.			

Average total amplitude of excursion of tendons at the various levels

	Above Wrist		*Level of Metacarpals*		*In Proximal Segment Digit*		*In Middle Segment Fingers*		*In Proximal Segment Thumb*	
	mm.	inches	mm.	inches	mm	inches	mm.	inches	mm.	inches
Wrist tendons	33	1¼								
Flexion Fingers										
Flexor profundus	70	2¾	35 6	1¼	19 6	¾	4 6	3/16		
Flexor sublimis	64	2½	35 2	1⅜	14 7	9/16				
Extensors Fingers										
Extensor digitorum communis and also proprius	50	2	16	⅝	3	⅛				
Thumb flexor	52	2 1/16	32	1¼					12	½
Thumb Extensors										
Extensor pollicis longus	58	2¼	15	⅝					8	5/16
Extensor pollicis brevis	28	1⅛	9	⅜						
Abductor pollicis longus	28	1⅛								

joints at once is also given, as indicated in the first table on p 47

Figures are difficult to remember, so the following may aid as a rough working basis. Total amplitude above the wrist

Wrist tendons	1¼ inches
Long flexors fingers	2¾ inches
Long flexor thumb	2¼ inches
Long extensors fingers and thumb	2 inches

Following repair most tendons have their amplitude of excursion more or less limited This usually means that they can, if repaired at the wrist or palm, move a few individual joints fairly well, but cannot move all of the joints at once. Thus our repaired tendons should have, in order to give full function the normal amplitude of excursion at each level, as expressed in the preceding tables Another application of advantage in knowing the excursion of tendons is in selecting the proper tendon to transfer to another to perform its work. The transferred tendon should have at least the full amplitude of excursion of the tendon for which it is substituted. Also, we should not transfer a tendon to two or more tendons which have different amplitudes of excursion, such as the extensor pollicis longus and abductor pollicis longus, as is further discussed under Tendon Transfers in Chapter 9

SURGICAL ANATOMY

Landmarks. The styloid process of the radius is almost one-half inch more distal than that of the ulna, and is easily felt. Its tip covers the upper one-third of the navicular bone. The tip of the styloid of the ulna marks the level of the radiocarpal joint and the curve of this joint rises proximal to the interstyloid line. The head of the ulna is prominent in pronation, but in supination the styloid process is what we feel in place of the ulnar head.

On the dorsum of the wrist the bases of the first, third, and fifth metacarpals can be easily felt. The most prominent central projection on the dorsum of the wrist is the styloid process of the third metacarpal which projects radiodorsally This projection which frequently receives the bruise in crushing injuries, is 1½ inches distal to and on a line with the prominent tubercle on the dorsum of the radius. Between these two points, as landmarks, is the carpus. The bases of the metacarpals can be located by a dorsal cross groove.

The tubercle of the radius, easily felt, lies between the tendons of the long extensor of the thumb ulnarward and the short extensor of the wrist. A line from this

tubercle to the external epicondyle of the humerus naturally marks the septum between the extensor muscles of the fingers and those of the wrist The long extensors of the wrist insert on the bases of the second and third metacarpals and the extensor ulnaris on that of the fifth The snuffbox lies between the long and short extensors of the thumb and its floor is composed of the navicular and multangular bones The radial artery crosses it beneath the tendons to dive through the first metacarpal cleft. Control of bleeding from this artery from here to the deep arterial arch in the palm is difficult.

The two sesamoid bones in the short adductor and flexor tendons of the thumb are readily felt, and so is the joint between the first metacarpal and the multangular bone Occasionally a sesamoid may be felt when present in the anterior capsule of the other metacarpophalangeal joints, especially in the index and even at the distal joint of the thumb Of the four projecting hooks on the volar aspect of the carpus, the pisiform and tubercle of the navicular are more easily felt, the hook of the hamate and the ridge of the greater multangular bone being deeper in the heel of the palm The tubercle of the navicular bone is at the base of the thenar eminence just beyond the distal flexion crease of the wrist and between the tendons of the long abductor of the thumb and the flexor carpi radialis. The pisiform bone is grooved at its base on its radial side and there it overhangs and protects the ulnar nerve and artery after they have penetrated the transverse carpal ligament to a position volar to it. The four bony hooks or projections, above mentioned, together with the transverse carpal ligament bound and protect the channel of the wrist, through which run the flexor tendons and the median nerve This channel is in the line of the forearm when the hand is ulnar flexed, but is angulated 25° radialward when the hand is straight with the forearm Therefore, the grip is stronger when the hand is in ulnar flexion

The cleft of the extended thumb is on a cross-line with the superficial arch in the palm from the ulnar artery and the deep arch from the radial artery is one-half inch proximal to it. The webs of the fingers are three fourths inch distal to the proximal finger joints and the digital arteries fork

FIG. 43 Topography correlating bones, joints, creases, webs, nails, and other soft parts. Skin is smeared with barium sulfate. Positions of thumb are at side and forward.

one-half inch proximal to the webs. The first dorsal interosseus muscle is prominent between the thumb and index metacarpal. It is composed of two parts, the superficial belly which can be felt to contract as the index finger abducts and the deeper part when it flexes the proximal joint of the index. Both bellies contract when pinching between the thumb and index finger either in the lateral or anteroposterior plane In cisions in the dorsum through this cleft should be kept radial to this muscle.

The carpal bones together are concave in their volar aspect and convex in their dorsal. There is hardly any motion in the carpometacarpal joints with the exception of that of the thumb, and here the multangular bone has in addition considerable motion as it moves with the metacarpal.

Of the other carpometacarpal joints, that of the little finger has more motion than the rest by a slight degree.

Volar Aspect of Forearm. The two central superficial tendons, flexor carpi radialis and palmaris longus, can be made to stand out by flexing the wrist against resistance. Opposing the thumb also brings out the palmaris longus tendon. Beneath this tendon or slightly radial to it is the median nerve. This tendon is unique in running two-thirds of the way up the forearm.

The deep fascia enclosing the long flexors in the forearm is tough and unyielding, so that pressure developing within its enclosure from trauma or obstructive venous engorgement squeezes out the blood supply and Volkmann's ischemia results. Within this space the long flexor of the thumb and the flexor ulnaris muscle fill in the two lateral aspects. In between them, occupying mostly the ulnar half of the space due to the crowding by the flexor carpi radialis, are the two layers of flexor digitorum, sublimis and profundus. The sublimis tendons are muscled much farther distalward than are the profundus tendons, and each muscle slip runs down to a point, while those of the profundus end squarely across. The *profundus tendons are on the same plane* and are parallel and larger, but the sublimis tendons of the long and index fingers cross each other. The floor of the space is formed by the pronator quadratus muscle and proximal to that the interosseous membrane, down which run the interosseous vessels and the nerve to the pronator quadratus. The flexor tendons travel straight through the wrist channel when the hand is ulnar flexed and then fan out to the digits. The tendon to the thumb runs through the radial bursa and those to the fingers *through the ulnar bursa.*

Dorsal Aspect of Forearm. The long *extensors of the fingers occupy the center* of the dorsum of the forearm and the long extensors of the wrist the radial part of the dorsum, the latter being especially prominent in the upper part of the forearm. Taking their origin from the interosseous membrane and adjoining parts of the bones deep in the forearm, the three extensor muscles of the thumb emerge from under the extensors of the fingers and roll over the extensors of the wrist to reach the thumb. Just within the V of the crossing of the long extensor of the thumb and the short extensor of the wrist is felt the radial tubercle. Arising in the same plane as the thumb extensors is the extensor indicis *proprius. The extensor proprius of the little finger* is in the same deep plane with the extensor digitorum communis and extensor carpi ulnaris. Higher in the forearm the supinator brevis is on the same plane with the thumb extensors.

At the wrist each extensor tendon has a separate synovial sheath with the exception that the abductor pollicis longus and extensor pollicis brevis share the same sheath and so do the extensor indicis proprius and the four tendons of the extensor communis digitorum. Thus, there are seven synovial sheaths on the dorsum, but only two on the volar aspect. The extensor digitorum communis and extensor digiti V proprius override the deep layer of *oblique muscles* and *lie in a trough* between the radial and ulnar extensors of the wrist. The nerve supplying the muscles in the back of the forearm emerges from the supinator brevis and lies between the superficial and oblique muscle layers.

Palm. The palm owes its toughness to the skin, subcutaneous fat, and palmar fascia, and these durable tissues protect the more delicate structures beneath. The skin is so tough it will not angulate for plastic maneuvers. The subcutaneous fat is in firm adherent lobules, each contained in a pocket of connective tissue. The palmar fascia sends septa and fibers to the skin and also deeply to the ligamentous tissues at the sides of the metacarpals. At the creases in the palm the skin is tightly held

by these fibers to the palmar fascia. The same applies in the fingers. The attachments, reaching from the metacarpals to the skin, maintain the hollow of the palm. A description of the fascial septa in the palm may be found under Dupuytren's Contracture in Chapter 5 In the distal part of the palm opposite each digital cleft is a soft prominence where the fat bulges rated from the interosseus muscles by the motor branch of the ulnar nerve and the deep palmar arch, from which they receive their blood and nerve supply A tiny nerve twig runs to the base of each lumbricalis muscle, two of which are from the adjoining volar digital nerves from the median, but the other two from the motor branch of the ulnar nerve, and should not be

FIG. 44 Topography correlating bones, joints, creases, and soft parts The skin is smeared with barium sulfate Positions of thumb are at side and forward.

through between the four slips of the palmar fascia as each of these continues down each finger Because of the firmness we do not find in the palm hematoma or edema so often found in the dorsum of the hand

Incisions to expose the contents of the palm are made through skin, fat, and palmar fascia, thus exposing the blood vessels of the superficial arch and the volar digital nerves The vessels of the superficial arch lie superficial to the nerves here, just as those of the deep palmar arch lie superficial to the deep branches of the ulnar nerve. Between these two sets of vessels and nerves are the sublimis and profundus tendons and the lumbricalis muscles The adductor muscles of the thumb are separated from the interosseus muscles by the motor branch of the ulnar nerve and the deep palmar arch, from which they receive their blood and nerve supply harmed by the surgeon nor should he injure the main motor branches from the median and the ulnar nerves. The former extends from the median nerve directly to beneath the deep fascia in the thenar eminence just beyond the anterior carpal ligament, and it may be in two parts. The motor branch from the ulnar nerve leaves the main trunk just past the pisiform bone

The transverse metacarpal ligament is a strong, flat band crossing between the heads of the metacarpal bones at their volar borders It separates the interosseus muscles and spaces behind from the lumbricalis muscles in front. The strong ligamentous annular sheaths of the flexor tendons arise

from this transverse metacarpal ligament, commencing just proximal to the meta carpal heads. Opposite the joint is a short gap, and then the second annular sheath continues to halfway down the proximal phalanx.

The skin of the palm and volar surface of the fingers contains more sweat glands than that of the dorsum of the hand and

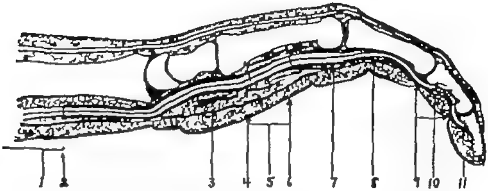


FIG 45 Sagittal section of fresh frozen hand through long finger Shows loose fat between extensor and flexor tendons and the bones, the undulating course of flexor tendons in finger loose fat with nerves and vessels beneath palmar fascia, tough subcutaneous fat, and joint spaces. 1 and 5 paratenon formation 2 and 4 limits of ulnar bursa 6 and 11 *limits of digital flexor sheath* 3 *palmar fascia* 7 *pulley at metacarpal* head 8 pulley at proximal phalanx 10 pulley at middle phalanx 9 flexion creases in finger separating the three volar fat pads—dangerous for puncture wounds, which, without the intervention of subcutaneous fat, enter directly into tendon sheath.

has an abundance of lymphatic vessels, but is hairless and almost devoid of subcutaneous veins or pigment. Lymphatics and veins all run to the dorsum of the hand and on up the arm. In hand and forearm venous *return is mostly external, as in the fetus,* and in contrast to the upper arm

Dorsum. On the dorsum of the hand there is more or less interdigitating of the tendons so that even if a tendon is severed the finger may still extend The tendon of the extensor indicis proprius is smaller than the extensor communis tendon to that finger, while that of the extensor digiti V proprius is larger Both of these proprius tendons lie to the ulnar side of their respective communis tendon The diagonal intercommunicating tendon slips just proximal to the knuckles, *aid in coordinating* extension of the fingers, which should work together Only the index and little fingers *extend freely alone.*

Fingers. There is a set of four nerves and arteries down each finger, but the dorsal two of these are not of much importance. The volar pair is on a level with the anterior volar border of the flexor tendons and the dorsal pair on a level with the dorsal border of the extensor tendon. Unlike in the palm, the arteries lie dorsal to the volar digital nerves.

The flexor sublimis tendon becomes flat and partially surrounds the profundus tendon just before it splits into its two flat *tendons of insertion.* It forms a three legged sling over the proximal phalanx to help hold the profundus tendon in its bed. The annular ligaments in a finger, ensheathing the flexor tendons, are opposite the proximal halves of the proximal phalanges and the central thirds of the middle phalanges, but are not present opposite the joints. They keep the tendons from bowing across the flexed fingers and add to the efficiency of their action. A description of the dorsal aponeurosis which can be readily palpated on the back of the finger may be *found in Chapter 10, Intrinsic Muscles of* the Hand.

The fingernails require about four months to grow their length and may show transverse grooves partly down the nail from an illness within the last four months At their sides and bases the nails curve more sharply, so this must be kept in mind in incising for paronychia. The lunula corresponds to what is practically a potential space, like an ungual bursa, the cellular attachment there being so slight that the space may readily fill with blood or pus The nails overlie the distal phalanges intimately enough to give firm support to the finger pulp

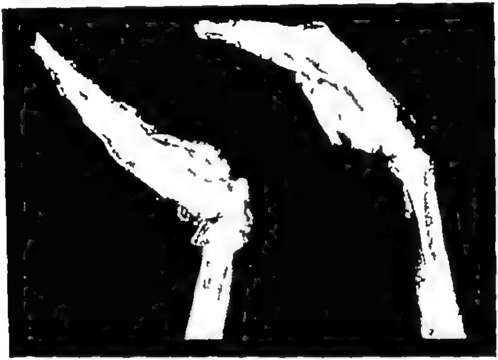


FIG. 46 Topography correlating bones joints creases, and soft parts with wrist in dorsiflexion and in palmar flexion.
Distal palmar crease is opposite the flexed proximal finger joints.
Two volar wrist creases bound the lunate.

Nerves. The applied anatomy of the median and ulnar nerves is described in Chapter 8, Nerves.

The division between these two nerve supplies runs from the carpus down the center of the ring finger crossing a few communicating branches, thus making a natural surgical pathway between them to the depth of the palm.

Throughout the fat of the palm and fingers are conspicuous yellow, zeppelin shaped bodies which are corpuscles of special sense, stereognosis being especially developed in the palm and fingers and particularly in that part supplied by the median nerve in contrast to the ulnar, the opposing surfaces between the thumb, and notably the index finger, being the most sensitive.

The radial nerve travels under the brachioradialis muscle This muscle has a conspicuous tendinous insertion well down toward the lower end of the radius Just above this insertion the nerve penetrates out through the deep fascia between the brachioradialis and extensor carpi radialis longus tendons, emerging at the easily felt curving border of the radius 2½ inches above the wrist to fan out over the first three metacarpals and bases of these digits.

The cutaneous nerves over the dorsum of the hand and wrist lie in the deepest layer of the superficial fascia and deep to the veins.

OSSIFICATION CENTERS

Times of appearance of bone in centers of ossification vary considerably with

health. They are delayed in disease, low nutrition, and vitamin D deficiency In inflammation, tuberculosis, or poliomyelitis they may come earlier Roughly their appearance is as follows

	Appearance
Radius, lower epiphysis	2nd year
Ulna, lower epiphysis	6th year
Thumb metacarpal, epiphysis at base only	3rd year
Finger metacarpals at distal end only	2nd to 3rd year
Phalanx, epiphysis at base only	3rd year
Some in proximal phalanges start in 12 months and in middle in 21	
Carpus	
Capitate	40 days to 8 mos.
Hamate	50 days to 10 mos.
Triquetrum	2 to 4 yrs.
Lunate	3 to 4 yrs.
Navicular	5 yrs.
Greater multangular	4 to 6 yrs.
Lesser multangular	5 to 6 yrs.
Pisiform.	9 to 15 yrs.

Fusion of the epiphysis of the ulna occurs at 14 years, but of the radius 21 years and of the metacarpals and phalanges 19 to 20 years In females these occur two to three years earlier The shafts of all bones of the hand, without any epiphyses showing, are present at birth. The whole carpus is car tilaginous The os centrale, which is present in most mammals, in man usually fuses with the navicular, but sometimes remains separate between the navicular, capitate, and multangulum minor Other carpal bones have but one center of ossification. The epiphysis of the thumb metacarpal is at the base, as in the phalanges, instead of at the distal end as in other metacarpals, though occasionally one is present at the base of the second metacarpal or at each end of the thumb metacarpal. The styloid process of the third metacarpal may develop from a separate center and may unite instead to the carpus.

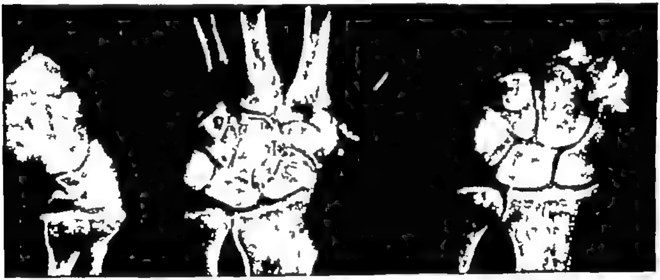


FIG 47 The two end x ray views are of a professional acrobat who walked on his hands much of his life and show hypertrophy in demand to use. The central picture is of an average normal wrist.

At birth the shafts of all bones of hand and arm are present but no epiphyses or carpals. In the carpus the capitate and hamate alone appear in the first year and then the others on the ulnar side, those on the radial side appearing later, and lastly the pisiform which is really a sesamoid bone.

SKELETAL MATURATION

A careful study has been made, notably by Todd, of the maturing of bone. He found that of the whole skeleton the hand showed the most constant changes chronologically, and he made an atlas of standards for ages from three months to 19 years by

which, from the appearance of the bones of the hand as shown roentgenographically, the age may be told The criteria used were not the times of appearance of centers of ossification or the actual measurements of growth, as these depended on fluctuating conditions of health, which influenced ossification by affecting the mineral supply and the preparation of cartilage for ossification, but were based on the changes in shape and relative measurements of the phalanges, metacarpals, and—with lesser reliance—on the radius. These vary much with age in the growing shafts and in the penetration of bone into their epiphyses and cartilage. Before the epiphyses show, the shafts of the phalanges and especially the metacarpals are used

At first the hand is short and broad, but by growth of the shafts of the metacarpals and phalanges it lengthens considerably through the first year and continously until matured At birth the metacarpals and phalanges have the roentgen appearance of short, wide, rectangular rods with similar lengths of digits and almost no differentiation in their contours Through the years to maturity great differentiation occurs in each bone until they finally attain their shapely shafts and ends Todd has tabulated these changes chronologically in his atlas in 40 standards for males and 35 for females Their maturation is alike until the age of 10, when it progresses faster in the female, being complete at 16 compared with 19 in the male. The accuracy was tested for the ages most difficult to determine—namely, between eight and 14 years —by Newell, who found the margin of error for these ages to be one year The accuracy is much greater in younger children

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PART TWO

RECONSTRUCTION OF THE HAND

3

Examination of the Hand

REPORTS

Accuracy and Completeness Essential In the previous chapter an attempt has been made to gain a clear conception of the normal hand. With this in mind, the pathologic aspects of the hand to be examined will stand out conspicuously The majority of crippled hands for repair are under the supervision of insurance companies, acting under the Workmen's Compensation Laws Our reports on our examinations, treatment, and operations on these patients are always on review From the claim adjustors they pass from doctor to doctor, and also before the courts, and by them we are judged. Therefore, for the patient and for our own sake we must be right. Our diagnoses, treatment, and final results are registered on paper and are subject to the criticism or approval of our colleagues Such healthy competition makes for better work and more complete and accurate records Once the habit is acquired we cannot afford to let down our standard just because we may be working on a private patient.

Making Reports. The making of records of hand cases in compensation work is time consuming To examine and record on a badly crippled hand is the work of an hour, and usually monthly check ups and reports are required thereafter The use of a dictaphone is essential. Our records should cover all positive findings, and because of the many times the reports must be reviewed and new check ups on the measurements made, they should be written for clarity and speed of review The examination should be systematic and the findings should be grouped separately on the pages under their special headings. A summary at the end should give the essentials in diagnosis and plan of treatment.

Sketches. Quick sketches on our own records are invaluable in conveying quickly and precisely the conception of the hand Better than words they show exact locations, shapes, and sizes of scars, amputations, or deformities. Positions of joints are accurately recorded, not only by measuring but by sketching the hand or its parts in full extension or in full flexion. These sketches, however, must be accurate and in correct proportions, especially for quick review preparatory to operating Any doctor can draw if he must. Long, drawn out, wordy reports cluttered with detailed negative findings are impossible to use, because they fail to give in the shortest time a clear conception of the case that is easy to grasp

Working System. The first examination is best done at one's own office desk with the comfort of a workable arrangement and one's examining instruments available. For postoperative cases, it is best to have their charts hanging on the out side of the doors of separate rooms This

allows a review of the chart before seeing the patient. The surgeon can refresh in his mind what was done at operation and what special after treatment is necessary and what precautions should be taken, so as not to rupture newly repaired nerves, tendons, or other structures. Two methods facilitate this one is to have a different colored paper for the operative sheet to make it easy to find, and the other is to place a white slip of paper on the outside of each chart, giving a summary of the operation and caution as to what not to do

HISTORY TAKING

The secretary should record the name, address, occupation, employer, insurance carrier, nationality, age, marital status, and whether a private or a compensation case.

Accident. One first records how the ailment was acquired. If an accident, certain data are essential was it while at work for an employer or not, that is, is it a compensation or a private case? In addition to the narrative of the accident one should record exactly how the force was applied, so as to estimate better what damage was done. This includes the position of the limb, the degree and direction of the force, the amount of crushing, and the amount and virulence of the contamination Then should follow an account of what was done, first aid treatment, time of hospitalization, and time away from work what was done at operation, by whom, and subsequent treatment or operations The time before final healing gives an index of the amount of cicatrization and damage of tissue. If force was used in later physiotherapy, injury of joints can be expected. What attempts have been made to return to work and with what effect? One should inquire about former accidents or ailments of the limb and about its condition before the accident. In a late case one should be suspicious lest a disability from another cause is, for the sake of compensation, being ascribed to the accident.

Complaint. Under the heading of Present Complaint one should record, and in degree of importance, what bothers the patient the most whether pain, tenderness, limitation of movement, weakness, or something else. Is he able to work, if not, why? The viewpoint of how much use to him is the hand is of primary importance.

Past History An account of the past history regarding former sicknesses or accidents and of the general condition at present should, of course, not be omitted, although all of the apparent pathology may be in the hand. Any general condition or disease that might have a bearing on the reconstruction should be stated. One should consider how much ordeal of sickness and operations following the accident the patient has already been through, and whether or not the patient is of the type whose joints are inclined to stiffen.

EXAMINATION

Whole Arm. Every examination of the hand should start with the shoulder The long protection of the hand in a sling or refraining from using it gives inability to raise the arm to the vertical, and limits external rotation at the shoulder The raising should be tested in the anteroposterior and lateral planes and notes should be made of both internal and external rotation at the shoulder At the elbow, limitation of extension and flexion and the degree of pronation and of supination should be included. Muscles, tendons, bones, joints, skin and nerves should be checked throughout the arm and especially in the forearm The size of these muscles is an index of the use of the hand, and local and general atrophy or fibrosis is indicative of special conditions. Note in degrees is made of dorsal, palmar, radial, and ulnar flexion of the wrist. The first two are with the goniometer

on the dorsal surface of the forearm and hand Lateral movements can be obtained by drawing center lines in each member of the limb one up the long finger to the center of the wrist and the other from here up the center of the dorsum of the forearm The lateral motions of the wrist can then be measured by the angles formed by these two lines.

Observation A good routine when examining the hand is first to gain what we

FIG. 48. Measurements of the limits of motion of the elbow joint are taken by the midline of the upper arm and of the forearm.

can by observation During this we should sketch the hand, outlining carefully all scars and making graphic notations of our findings on the sketch The sketch conveys much of the general condition of the hand, the posture, deformities, and amputations. In our observation we should note the general trophic condition, or state of nutrition, of the hand, color, cyanosis, coldness, presence and size of pulse We should decide whether it be due to strangulation by scar tissue, impoverishment from obstruction of blood or lymph vessels, to some trophic condition from injury of the nerves, or to vasomotor causes The wear is an indication of work and it should be compared with that in the opposite hand as should swelling and edema also Fortunately, we usually have a basis for comparison as the two hands should be similar

Among deformities to be noticed is the position of the hand in its various joints Are the joints in the position of function, and if not, what is the cause? Is flat hand present, with loss of the carpal and metacarpal arches? Does the thumb oppose well or is it at the side of the hand, and are the proximal finger joints in hyperextension, or are the finger or any other joints in abnormal position?

Movements In testing the movements a conception of what the patient can and cannot do may be gained quickly by first having him, unclothed, perform at command all the normal movements in their full range from the shoulder down It is best not to touch the patient in this test, with his own limb the physician can show the patient what to do

The patient is told to do the following raise the arms vertically, face the palms outwards and then face the palms backwards, with arms forward place palms up and around and return to palms up circumduct the arm through the normal range, *with elbows forming right angles, rotate* the shoulders internally and externally, or similarly for rotation touch the dorsal spine and the back of the neck respectively with the hand, shrug the shoulders move the scapulae around and lean with the hands against the wall He is told to flex and extend the elbow, and with his elbow resting on his knee or on a table to turn to the palm-up and then the palm-down positions

To test the hand, he is instructed to flex the wrist dorsally, volarly, radially and ulnarly, to dorsiflex the wrist and extend the fingers, and to volar flex the wrist with the fist closed. He is told to extend his fingers and to flex them completely With the fingers he should touch the distal and also the volar parts of the palm, and demonstrate lateral motion He should flex their proximal joints and at the same time extend their distal two The thumb is put through the complete range of circumduction, from back of the hand to opposition and on to touch the base of the little finger It is fully extended, fully flexed and made

to scrape in the straight position across the palm and to make a strong O with the index finger Knowing the normal ranges one can by these tests determine quickly just what the patient is unable to do, and wherein lies his disability

The manner of moving is indicative. If he will not try, one suspects malingering

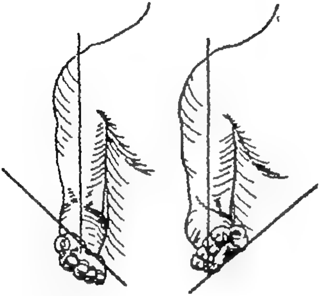


FIG. 49 Measuring degree of supination and pronation. The arm is held vertical and at the side. The forearm is at a right angle to it and the elbow is held immobile. Measurements are of the angle between the midline of the arm and the line of the palm.

If he cannot make the hand move, a dissociation between hand and mind is suggested He may be protecting the hand from the pain of causalgia or Sudeck's atrophy, or the dissociation may be from long disuse. Moving of the hand with great tremor and sweating indicates neurosis or vasomotor instability Accompanying these conditions there is much actual stiffening of the joints

In recording movements one should give in degrees the angle of flexion and that of extension, but should specify in each instance whether it is voluntary or passive Without this the figures are ambiguous and hence useless. Whenever necessary the similar measurement in the normal or other hand should be given for comparison

FINGERS Movements of fingers as a whole should be recorded. One can state that each finger lacks so many inches of full extension when measured at the tip This measurement is taken from a plane surface laid on the dorsum of the hand. Similarly, for flexion we state that each finger lacks so many inches of flexing voluntarily to the distal crease in the palm and so many passively This measurement is taken from the composite distal palmar crease to the nearest part of the pulp of the finger Roughly, we can express degree of motion of a finger in the proportion of the arc the finger tips describe in passing from full extension to full flexion, thus, the fingers may flex through the first two-thirds of their normal range of flexion, or in another case may lack their last third of extension.

We should also give in table form, and expressed in degrees, the measurements of each of the individual finger joints. This should be done for both extension and flexion and for voluntary and passive movements, remembering that unless voluntary or passive are specified, measurements are useless. To measure the degree of flexion of a finger joint the goniometer is laid along the dorsum of the finger each way from the joint. The phalanx proximal to the joint measured is held from moving by the examiner, but care must be taken not to hold this on a strain of extension while the measurement of flexion is being taken, or vice versa, for fear of erroneously recording automatic movements. Flexion of individual joints may be greater, testing each joint separately, than if the joints are measured with the finger as a whole flexed.

Convenient table forms for expressing movements of fingers are as follows

The fingers lack of extending to a straight line as measured at their tips as follows

	V	P
Index		
Long		
Ring		
Little		

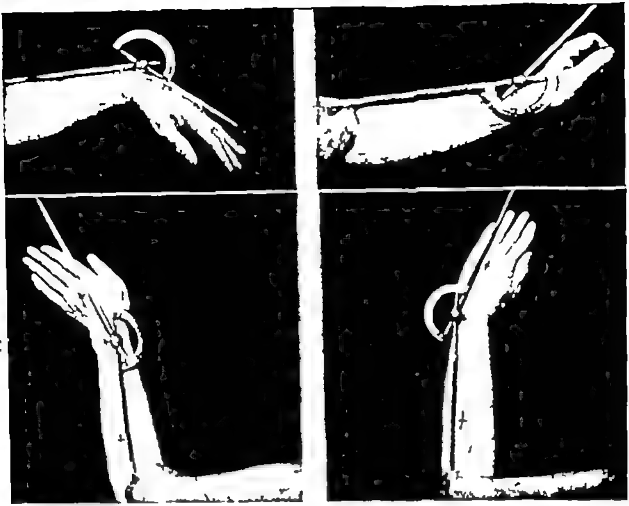
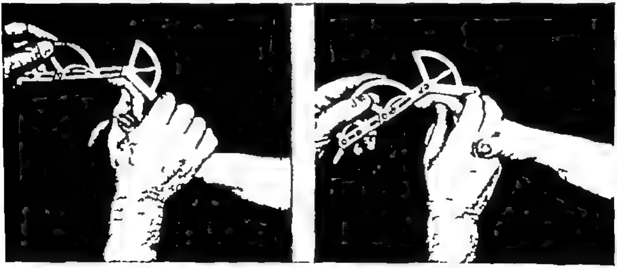


Fig. 50 Measuring the motions of the wrist joint.
(A and B) Flexion and dorsiflexion are measured by the dorsal surface.
(C and D) To determine adduction and abduction the midline of the forearm and of the third digital ray are marked with dots using the central dot over the center of the carpus as the apex of the angle.



A B

Fig. 51 Measurements of voluntary and passive flexion of each joint of a finger are taken along the dorsal surface.
(A) Incorrect method of measuring voluntary flexion because the examiner's hand is overextending the finger thus causing automatic flexion of the distal joint.
(B) Correct method refraining from overextending the finger
These are the ways of holding a finger in exercising to make the patient voluntarily pull the flexor tendon through the finger.

Lack of extension of the individual finger joints as measured in degrees is as follows

	Proximal jt. V	Proximal jt. P	Middle jt. V	Middle jt. P	Distal jt. V	Distal jt. P
Index						
Long						
Ring						
Little						

Of flexing to the distal crease in the palm the fingers lack as follows

	V	P
Index		
Long		
Ring		
Little		

Flexion of the individual finger joints as measured in degrees is as follows

	Proximal jt. V	Proximal jt. P	Middle jt. V	Middle jt. P	Distal jt. V	Distal jt. P
Index						
Long						
Ring						
Little						

The following abbreviations are useful D C, distal crease, V, voluntarily, P, passively, VP, voluntarily and passively

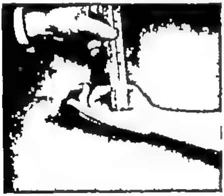


FIG. 52 Measurement of the limitation of the finger of voluntarily flexing to the distal crease in the palm. Measurement is from the pulp of the finger

It may be noticed that the fingers flex completely to their bases, but do not flex in their proximal joints or if their proximal joints flex well the fingers may touch the palm proximally or a certain distance proximal to the distal crease in the palm, but may lack so much of touching the distal

A B

FIG. 53 (A and B) Determining the amplitude of voluntary motion in a finger as measured at its tip.

crease. One can state how far proximal or distal to the distal crease in the palm the fingers touch To express the practical degree of flexion of fingers one may state such as the following "The hand cannot hold one or two of the examiner's fingers, but can grasp three of them weakly and four of them strongly," or "can grasp one or more of the examiner's fingers strongly"

BONES Note should be made of any deviation from the normal in contour, length and alignment, especially as regards position of function and muscle balance. The bones must be right for correct mechanics X-ray films of hands should be taken in three views anteroposterior, lateral and oblique. A stereo picture, especially of the carpus, is useful

THUMB In describing the thumb, its position with reference to the hand is noted whether it is at the side or in back of the hand, or in a position forward from it. Measurements are made of limitation of extension, of flexion and adduction, and of opposition. Of these, the former is measured by placing the two hands palm to palm, with the fingers reaching equally, then the normal thumb is voluntarily fully extended and bent backwards. The examiner from this marks a point in space where the injured thumb would be in a similar symmetrical position, and measures with a ruler how many inches it lacks of reaching it both voluntarily and passively In testing for flexion and adduction, the normal thumb is made to reach as far as it can

FIG. 54 Measuring the limitation in inches of voluntary extension of fingers measured at their tips. Should be done while the wrist is flexed, straight, and dorsiflexed. One ruler marks the plane of the hand the other shows the limit of extension of the finger as measured at its tip.

down the ulnar border of the hand Measurements are taken in the injured hand of how far the thumb fails to reach this point.

The above are expressed "The thumb lacks of extension so much and of flexion and adduction so much"

Opposition is expressed in two measurements one is the farthest distance forward from the hand the pulp of the thumb will reach when it is opposite the base of the long finger, or if it cannot adduct that far the measurement can be made opposite the base of the index finger The other is the *angle the nail makes with the palm* when so doing The normal angle is zero in full opposition, as then the nail is parallel with the palm, and when the thumb is at the side of the hand the nail normally is at a right angle to the palm

The spread of the thumb can be expressed by the angle between the first two *metacarpals, by the angle the thumb makes* with the radial border of the palm, or by how far the tip of the thumb spreads from the radial border of palm or index finger Measurements are also taken of limitation of both voluntary and passive extension and flexion of both the proximal and distal joints of the thumb

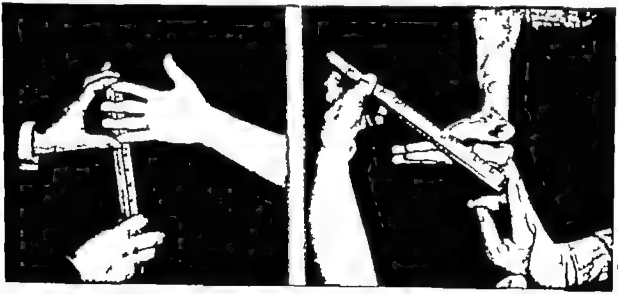


FIG. 55 (*Left*) Measuring the spread of the fingers and feeling the strength of spread.
FIG. 56 (*Right*) Measurement of limitation of voluntary extension of thumb The two hands are placed *symmetrically together* The normal thumb spreads and extends backward to its maximum and a finger is placed in space at a point symmetrical with the tip of the normal thumb. Measurement is taken of how far the tip of the injured thumb lacks of reaching this point.

A B

FIG. 57 (A) Measuring limitation of flexion and adduction of thumb Measurement is taken from a point on the injured hand corresponding to the limit of this motion in the normal hand.
(B) Semilateral view of attempting to adduct and flex the thumb
The method of measuring the degree of opposition of the thumb is described in Chapter 10

In recording limitations of motions of joints, it should be stated whether the joint shows signs of inflammation or not, such as general tenderness or swelling throughout its circumference, or whether limitation is due to some special adhesion or shortness of capsule which may show by local pain or tenderness. On any suspicion of joint or bone trouble *x ray films should be taken*

Contractures. Cicatrices of skin are recorded by measurements of size and by sketches with accurate proportions The digits and wrist are bent in the opposite direction to ascertain if the scar whitens on tension and to bring out the lines of tension in the scar where keloids will form Firmness and degree of fixation of the skin to the firm underparts is tested by attempting to slide the skin, or by having a tendon move beneath the skin while the skin is held. Scars contract, so we must be alert to the results of this, such as deformity of joints and bones and circumferential strangling of vascular and nerve supply, resulting in defective nutrition and hampering movable parts in general In a flexion contracture we should ascertain which of the various tissues is causing it. In contractures one should record an estimation of the size of the defect of skin or nerve by imagining the amount of extra material necessary to allow the limb to extend fully

Tendons. Tendons can generally be felt to move beneath the surface, especially if the movement is against resistance. We should test to ascertain whether a tendon is severed or adherent, or perhaps trying to work against an adherent antagonist or to move a stiffened joint. One should test to ascertain if one tendon is adherent to a parallel tendon, as sublimis to profundus, or whether the tendon bows across the joint from loss of an annular band

Pain and Tenderness. When pain and tenderness are present, their location and cause can be sought for by straining the parts of the hand in different directions until it is ascertained what particular tissue causes the pain. This may be a tendon, muscle, joint, ligament, or bone, or it may prove to be a neuroma or tender nerve. Activation of a certain muscle may produce the pain either by voluntarily contracting against resistance or by passively over stretching the muscle, indicating the cause of the pain to be at the insertion or origin of the muscle. The pain may be located by reproducing it by squeezing bones together, moving them against themselves, or by shoving up in turn through the carpus and bones of each separate ray

A tender area should be accurately outlined with ink. To do this, the end of a finger or lead pencil rubber approaches the area from all sides, pressing intermittently as it goes and marking with ink each spot where the tenderness commences.

In testing the grip, one should obtain an average from three trials with each hand *without the patient's seeing the instrument.* Note should be made whether right or left handed. Further tests can be made for skill and endurance.

In examining we should cover all tissues, skin, bones, joints, tendons, blood vessels, and nerves, and not overlook the factors of nutrition, vasomotor changes, or functional conditions.

Practical Use. The practical aspects of function for use of the hand in work should always be kept uppermost the width of the spread for grasp, the opposition of the thumb, and the size of the object that can be held Notes should be made of how much of each finger the thumb can touch and if the joint positions will allow use Important functions are grasping with the hand as a whole, between thumb and fingers and palm and fingers, large and small objects with strength, firmness, and agility

Nerves Examination should cover the three nerves of the hand and their branches for motor, sensory, and trophic functions Areas of anesthesia to light and coarse touch and of analgesia to pinprick should be accurately plotted on sketches and also those of paresthesia and hypo- and hyper sensitiveness and the exact spots of sensitive neuromata Motor function is shown in the action of the intrinsic muscles of the hand. Areas of trophic change, due to lack of nerve function, can be outlined by sight and touch. Signs of vasomotor disturbance, such as sweating, pallor, flush, cyanosis, blotchiness, and pathologic skin texture should be included

Signs of nerve lesions are so typical that often a glance will lead to the diagnosis. Postural deformity, atrophy of muscles and skin, and anesthetic areas are characteristic of lesions of each single nerve, of a combination of nerves, or of the brachial plexus. Ulnar palsy shows the typical clawing of the last two fingers, intrinsic atrophy, especially of the first interosseus and the hypothenar muscles Median palsy shows the thumb at the side atrophy of muscles of opposition and the feel of skin atrophy, and anesthetic areas, in the median instead of the ulnar, distribution. Combined median and ulnar palsy shows an atrophy of all of the intrinsic muscles, thumb at the side loss of the metacarpal arch, clawing of all fingers and the feel of skin atrophy, and an anesthetic area over the whole volar surface Radial palsy in contrast, shows wrist, finger and thumb drop Muscle atrophy and paralysis up the arm is typical for each nerve, hand paralysis for lower brachial palsy and shoulder paralysis for upper These gross signs quickly orient one before he makes a studied survey

Tests for nerve function will be found in Chapter 8, Nerves.

General Examination The general physical examination preoperatively should not be overlooked, and especially the condition of the heart, lungs, blood pressure, and urine. It is important to know of general tendency to arthritis or stiffening

If a splint is to be made, the hand measurements are taken by comparing to one's own hand or tracing on paper Now is the opportunity to obtain photographic records.

DIAGNOSIS

The examination and diagnosis of a hand takes time and thought. The thought develops as we gather our data in making the survey, and at the conclusion we summarize by listing as the diagnosis all of the features which are pathologic.

Pathology May Be Higher One should not drop into the error of assuming that the disability in the hand is due to pathology there, for instead it may be the result of a general ailment which is affecting the hand. Various diseases of the spinal cord—such as syringomyelia, poliomyelitis, and the various atrophies of the cord or dystrophies of the muscles—may show themselves in the hand It is not unusual for all attention to be directed to the pain, circulatory, or nerve changes in the hand, only to find that it is due to scalenus anticus syndrome, cervical disk, or perhaps from an overpulled brachial plexus The effect of trauma or pressure from tumor may be located in the nerves of the arm and give symptoms in the hand

Not only should we be alert to causes of hand symptoms originating elsewhere but, in order to avoid the sin of omission, we

should in case of injury to a part always seek some other injury incurred at the same time. The diagnosis of a hand condition is often obscure, but if we find any one point it pays to run it down thoroughly throughout all its ramifications. *If we don't hunt, we don't find.*

Interpretation of Limitation of Movement. Many different factors can limit the normal range of motion of a digit. We *should first determine whether it is voluntary or passive motion that is limited.* In the former case the nerve, muscle, or tendon that should execute the motion fails to do so. In the latter case of passive limitation, the trouble may be in the joint itself or in a flexion contracture which hinders the motion, or it may be that the antagonistic tendon or muscle may be holding back the motion because it is adherent or too short. In other words we should determine which is to blame the activating apparatus or the hold-back apparatus.

If passive motion is greater than voluntary motion, the tendon is not pulling If passive motion is equal to voluntary motion, the trouble is in the joints or due to fixation of the opposing tendons or tissues If voluntary motion is limited and passive motion is complete, the joints or opposing tendons or tissues are exonerated If, though, voluntary motion is limited and passive motion is also limited but not so much, then we know that both of the above factors are to blame, but that the primary trouble is that the tendon does not pull and that the joints or opposing tendons or tissues have secondarily become involved and are contributory to the limitation of motion

If a digit does not extend voluntarily, but can be extended passively, we know that either the extensor tendon or tendons are severed, or are adherent proximally, that their muscle is injured, or that the radial nerve or its posterior interosseous branch is injured. If the tendon be adherent on the dorsum of the hand the position of the wrist will not affect the lack of extension of the finger, but if it is adherent above the wrist then flexion of the wrist will make the finger extend. If flexion of the proximal finger joint causes extension of the middle finger joint, the extensor tendon is adherent on the dorsum of the hand A test is to *hold the proximal joint passively fully flexed.* The finger then extends stiffly in its distal two joints, resisting any attempt to force it into flexion

If there is neither voluntary nor passive *extension of the digits but still we find that if the wrist is flexed the digit can be voluntarily extended,* we know that either the flexor tendons or muscles are too short or are adherent above the wrist. Again, if the digit will not extend voluntarily or passively unless the proximal finger joints are flexed we know that adhesions hold the flexor tendons in the palm. If, however, the digit will not extend voluntarily or passively, irrespective of the position of the wrist or proximal joints, we know that either the finger joints are to blame or there is a flexion contracture within the finger, such as would be caused by adhesions to its flexor tendons or by contracture of the other volar tissues.

If the finger extends well in the proximal joint but poorly voluntarily in the distal two joints, although they extend passively, the intrinsic muscles or tendons are to blame—either through severance, adhesions, or loss of nerve supply When fingers will not completely flex voluntarily but do so passively, the flexor tendons are not pulling. The intrinsic muscles in the hand, however, should still be able to flex the proximal finger joints unless they, too, are injured If there is no voluntary flexion *at all of the middle or distal finger joints,* the flexor tendons are either severed or adherent, or the trouble is with the muscle or nerve supply

If the adhesions are in the palm or forearm, *flexion of the proximal joints* will allow the fingers to be extended. If, though, this has no effect on the extension of the distal two joints, the adhesions to the tendon are within the finger or there is flexion

contracture within the finger itself If the adhesions are in the forearm, the fingers will extend if either the proximal finger joints or the wrist be flexed

To locate the point at which a tendon is adherent anywhere from forearm to digit, commence proximally In the case of an extensor, first tense the tendon by holding the wrist passively on a strain in flexion Then, if the adhesion be above the wrist, the tendon will tense firmly and the digit cannot be flexed passively It can readily be flexed, however, if the tendon is relaxed by dorsiflexing the wrist If it is not affected by wrist motion, tense and relax the tendon by flexing and extending the proximal finger joint. If tension limits flexion of the distal two joints, and relaxation does not, the adhesion is in the dorsum of the hand If not, try, in turn, the middle finger joint to determine if adhesion over the proximal finger segment limits flexion of the distal two joints An adhesion to a flexor tendon is similarly located, using the reverse movements of wrist, proximal and middle finger joints in turn, first tensing then relaxing the tendon proximally Where an adhesion is present the tension produced will be so firm that there will be no slack for motion distally

If, when in full flexion, the finger tips touch the bases of the fingers or the distal end of the palm only, but cannot touch the remainder of the palm either the proximal finger joints are to blame for this lack of flexion, adherent extensors, or the intrinsic muscles of the hand which should flex these proximal joints are not functioning The usual cause for limitation of flexion of these proximal joints is contracture of their collateral ligaments, due to the effect of former infection in the palm temporarily paralyzing the intrinsic muscles or to prolonged immobilization of these joints in the straight position especially in the presence of inflammation edema or reaction from trauma If when the fingers flex, their tips touch the proximal end of the palm but cannot flex to the distal crease in the palm, the middle or distal joints, or both—or limitation of excursion of the flexor or extensor tendons—are to blame

Loss of lateral motion in a finger is due to loss of function of the interosseus or lumbricalis muscles, or to the cicatrix of a flexion contracture at one side of the base of the finger

Limitation of spread of the thumb from the hand is usually due to the accumulation and contraction of scar tissue between the first two metacarpals as the effect of trauma or infection in the thenar space or ischemic contracture of intrinsic muscles If there is loss of voluntary opposition of the thumb, but this is present passively, the median nerve is injured, affecting its motor thenar branch, or the opponens pollicis and flexor brevis pollicis muscles have been injured If, though, the thumb does not oppose either voluntarily or passively, the cause may be in cicatricial adhesions between the first two metacarpals, dorsal scar, or it may be due to fixation by adhesions of the tendon of the extensor pollicis longus muscle. It also may be due to ankylosis of the carpometacarpal joint, or it may be postural as part of a flat hand from flat splinting If the base of the thenar eminence rides forward and there is not proper muscular control of the thumb, the tendon of the abductor pollicis longus has been severed or the hand has been displaced backward by a midcarpal dislocation.

A test for presence of sublimis is to hold the finger voluntarily with the proximal and middle joints at right angles and then to find that the distal joint is flail.

If one finger has been injured, so that its flexion is much limited, and we find that the other fingers—especially the adjoining ones—do not flex completely, the cause is usually that the flexor tendon of the injured finger cannot be drawn proximally through its full excursion by the common flexor profundus muscle. Therefore, being held, this common muscle cannot fully flex the adjoining fingers. This also occurs when the one finger has a short amputation

stump and the flexor profundus tendon is adherent within it, as the amplitude of motion of the tendon in moving the short *stump is much limited, thus robbing the* adjoining fingers of ability to flex completely One can readily test for this condition of one tendon holding back the others by grasping the similar finger in the other hand, while holding it in extension and instructing the patient to make a fist. The same degree of limitation of flexion in the other fingers will then be seen in the good hand as in the injured one Similarly, when one extensor tendon is adherent in the dorsum of the hand, or the proximal finger joint of one finger is held in flexion contracture, the extensor digitorum communis muscle may not be able to extend the adjoining fingers When extensor tendons are adherent on the dorsum of the hand, the fingers flex in their distal two joints, but the proximal joint remains straight.

If the intrinsic muscles interossei and lumbricals, are working, the distal two finger joints extend well when the proximal joint is straight, the lateral bands can be felt *to move voluntarily when the finger is* straightened against resistance, and each finger shows lateral motion

If intrinsic muscles have contracted as in local Volkmann s ischemia or local scar, proximal finger joints will be held flexed, the distal two straight and the thumb clumped into the palm A test for short interossei is to hold the proximal finger joint fully extended and find that then the distal two joints cannot be forced into flexion

When fingers cross each other on flexion, it is due to a tipping of the axis of the proximal finger joint. This may be from malunion in rotation of a fracture of the metacarpal or it may be due to amputation of either the middle or ring fingers, including the head of the metacarpal This robs the adjoining metacarpals of the side support of the missing head, so the axes of the proximal finger joints of these adjoining fingers tip toward each other A cause which may act alone or modify the above is surface scar contracture either on the dorsal or volar aspect, which may roll the *metacarpal heads towards each other*

If a finger which flexes well passively can flex voluntarily in its proximal and middle joints but not in its distal joint, either the profundus tendon is not working or else the profundus and sublimis tendons are adherent to each other, so that the motion has effect on the middle joint only In this case, if we hold the finger in partial extension in its middle joint, we may see some flexor action in its distal joint.

Flexion Contracture. Limitation of extension of digits by flexion contracture may be due to many causes, affecting any or all of the various tissues from skin to capsule of joint. Usually one tissue is primary and the others secondary, until finally all are involved If the skin is primary it will whiten on attempts at extension, but not if the contracture is due to deeper tissue. Commonly, flexor tendons become adherent within a finger, or due to past infection in the finger there is contracting cicatrization *in all of the tissues in its volar aspect.* A median longitudinal volar scar is frequently to blame. If a history is given that the finger was forcefully overextended and contracture is found within the finger, the cause is usually from contracting cicatrization, *resulting from a rupture of the anterior* capsule of the joint, usually the middle one If the fingers and wrist were both overextended, the contracture is usually due to shortening of the forearm flexor muscles following overstretching or multiple rupture within these muscles.

If the flexion contracture is due to the condition described by Dupuytren, it will be seen to be in the palmar fascia and involving the skin in the characteristic cross-wrinkles and hard plaques, with loss of subcutaneous tissue. The bands may run down the fingers. If the contracture is of the type described by Volkmann, there are signs of shortening of the flexor muscles of the forearm, so the fingers cannot be

extended unless the wrist is flexed These muscles will show atrophy and hardness and the hand will show nerve changes and the typical position of flexed wrist, clawed fingers, and thumb at the side There will be history of venous obstruction at the elbow

In diagnosing, errors will be frequent if we jump to a conclusion too quickly We should test all possible causes for limitation of motion, flexion contracture, nerve lesions, etc., and weigh carefully before commitment.

MALINGERING

A considerable number of hands show either functional condition or one of out and-out malingering, which puts to test the credulity and ingenuity of the physician The patient may have been through the compensation courts before and know the ropes, or he may be of the scheming type, or may be receiving lodge or insurance benefits on the side so that together with his compensation he makes more crippled than well.

The anesthesia may be glove-like instead of conforming to the anatomic nerve supplies, or the patient may be taken off his guard and answer as instructed when his eyes are closed to say "yes" when he feels and "no" when he doesn't. Anesthesia without trophic changes is not natural, nor is paralysis without atrophy When asked to move his hand in a certain way he may show not the slightest effort to move it and a finger laid on the muscle will verify this, or he may tighten both flexors and extensors at the same time so that his digits do not move. If the examiner can induce him to relax, one can rhythmically move the finger and feel voluntary resistance from the patient's efforts to show that it cannot move. By diverting the attention, the finger can be passively moved through the complete range The patient may then on command hold that position, showing that he has power of complete flexion Some who are not malingerers develop the habit of tightening both flexor and extensor tendons when they attempt to flex. They can, however, usually be taught to correct this The usual position of the hand held by a malingerer is that we use in thrusting the hand through a sleeve Tests by the electric current make it difficult for him He

FIG 58 Case O B Patient claimed that two months previously he struck his right palm against the edge of a counter Has complained ever since of pain numbness and inability to move the hand. Has glove anesthesia to three inches above wrist. Would not make slightest effort to move hand, but enough effort to keep the one position. All objective signs were negative. Conclusion Malingerer seeking compensation

sees his muscles which he claims to be paralyzed snap into action by the galvanic or faradic current with no sign of reaction of degeneration, and if the current is fairly strong and applied over the nerves at the elbow, the digits, in spite of his efforts to prevent them, will show full flexion Rarely, however, does a malingerer admit he is faking, even in face of a clear demonstration.

The claim of pain may be disproved by a battery, an intervening sensitive galvanometer, and two poles placed a few inches apart on the skin In case of real pain or emotion, sufficient sweat pours out on the surface of the skin to register in the galvanometer the increase of conductivity for the electric current between the two poles Of real practical help is the use of a detective who makes friends with the pa

tient on the outside and gathers incontrovertible evidence and moving pictures of the limb functioning normally

WRITING REPORTS

In reconstructing hands, there is much work in keeping up adequate reports that imposes necessary but important drudgery which is unavoidable in compensation work. It is what makes private surgery easy in comparison. Even though demanding of work and the burning of midnight oil, the maintaining of accurate typewritten reports and records of results is well worth while. These records of examination, operation, and monthly check ups are continually being referred to in the many months of treatment and following the case. They finally include the outcome of the surgeon's work in terms of remaining permanent disability They are necessary for use in court and invaluable for one's own future reference.

This portion is written as a guide for the newly arrived novice in industrial work, whose duty will be to keep up the reports It is based on his mistakes and needs

Insurance Aspect. There are certain aspects which, from the standpoint of the *insurance company, are essential to be kept* in mind and to include in the reports. such as the following

Is the ailment presented due to an injury and to that particular injury in question, did it happen from some previous injury, or is it due to disease or any other contributing factors? Did the accident cause the condition or merely light up a preexisting one? Was it sustained while at work or outside of working hours? Early estimation of prognosis is necessary, so that the insurance company can lay aside in its books sufficient to cover the probable expense that will be incurred on the case. In the report of the final examination at the termination of the case they need accurate data, giving the measurements of movement and the exact degree of permanent disability, so that a rating can be arrived at. In a case coming for surgical reconstruction, data must be given to show whether or not the surgery will prove to be worth while. Will the amount in the permanent disability rating to be saved if reconstruction is done be more than the expense incurred in reconstruction? Also, from a humanitarian side, will the reconstruction be worth while in getting the individual back to the status of self-support?

Paint the Picture in Words. We should endeavor to include in the report the data that are desired and a true picture of the condition of the patient, making the report clearly understandable by thinking in terms of thoughts of the readers, who will be both medically educated laymen and physicians.

It is well to orient the reader early as to the nature of the case and to simplify the report at the beginning of the examination by stating that the pathology is limited to a certain anatomic area, as in the following example "In the right upper extremity, the thumb, wrist, and all proximal are normal", or "The injuries are limited to the right hand and forearm and left hip" The report should be systematized, grouping the thoughts separately under their various headings, such as appearance, deformity, scars, motions of wrist joint, motions of fingers, and motions of thumb, bones, and joints, also, the condition of the nerves and the general nutrition of the hand. The lesions of hands are so variable that the grouping is individual for each case Simple, straightforward, descriptive language is preferable to the ultrascientific, as the object is to convey the thought as directly as possible. The common fault is to crowd a report full of measurements that do not paint the picture, even to those familiar with them. A few summarizing *descriptive sentences clarify the picture for* the reader

As a preliminary to giving the measurements of flexion and extension of fingers, such generalizing terms as this are useful "Voluntary flexion of the fingers is considerably limited, as shown in the following table, although passive flexion is to good degree"

The measurements can follow these word pictures, so as to give the accurate detail This can best be done by utilizing such tables of measurement as given in the first part of this chapter

Ambiguity and Clarity Ambiguities are best avoided The following is an example If we describe the finger joints as first, second, and third joints, we will be misunderstood, as not all people start to count at the same end of the finger Similarly, if we speak of the first, second, and third fingers, some people will commence to count from the thumb It is preferable to use the terms proximal, middle, and distal finger joints, and the terms index, long, ring, and little fingers and thumb If we include thumb we can say digits, but otherwise fingers When we give the measurements of limitation of motion we should give the reason why the motion is limited and carry the complete thought through This spares the reader from carrying the figures in his head and thinking out the diagnosis For instance, in speaking of the left long finger after stating the exact degree of limitation of flexion in distance from finger tip to palm and the degree of flexion of each individual joint, one adds "because both flexor tendons to that finger were severed in the palm and are now pulling in a limited excursion through intervening scar tissue." Also, measurements of the degree of the limitation of extension of that finger are followed by such a statement as "because the distal portions of the flexor tendons have become adherent in the distal part of the palm, thus preventing extension of the finger" In this way one can associate for the reader the technical data with the conclusions to be deducted from it.

Practical Use One should keep always in mind the practical point of view, as to the use of the hand, including position of function, spreading of the thumb from the fingers to reach around an object, and flexion of the thumb and fingers for firmly grasping it, the size of objects that can be grasped, and the strength of grip and actual use of the hand Equally important is to give the area of sensory loss, because a hand without sensation in the area supplied by the median nerve is unfit for work

Conclusion In the conclusion, after determining, if necessary, whether the disability falls under compensation or not, the diagnosis is given by listing the various features of the hand that are pathologic The prognosis is stated, especially from the standpoint of use of the hand for work and how much improvement can be expected by natural processes If the outlook can be sufficiently improved by treatment or reconstructive surgery, there should be a brief statement of what should be done and just how much improvement from it can be expected

EXAMPLES OF REPORTS

Appended are a few reports of sample types In these the past history, general condition, and general examination are omitted because of lack of space

Short Report of Ulnar Nerve Injury

Case No August 26, 1940
Emp
Inj F T Age 28
Date of Inj May 21, 1940

Accident On May 21, 1940, while driving a caterpillar tractor along an irrigation ditch, the tractor nosed forward and threw him through the windshield, deeply lacerating the ulnar volar aspect of the left wrist

Several hours later, at Klamath Falls, Oregon, Dr ——— and Dr ——— did an extensive primary repair of the severed

flexor tendons and ulnar nerve under general anesthesia. He remained in the hospital four weeks because of infection. Complete healing occurred about August 7, 1940, but the wound was reopened on August 8, 1940, because of a flare-up of the infection

Complaint The ulnar half of the hand is numb, and he is unable to close the fingers for grasp

He is right handed.

Examination In the left upper extremity the shoulder and elbow are normal

All motions of the wrist are practically complete.

The thumb and fingers show the typical picture of ulnar paralysis. The thumb is without voluntary adduction, as on scraping the palm its tip leaves the palm at the ulnar edge of the index finger, and on flexion and adduction it lacks 1¾ inches voluntarily and 0 passively of being complete compared to the right. On pinching there is weakness and the arch of the thumb drops. There is considerable atrophy of all the intrinsic muscles of the hand supplied by the ulnar nerve, the circumference of the left hand being 7¾ inches compared to 8¼ on the right.

The ring and little fingers are held in the typical deformity of ulnar paralysis with hyperextension of their proximal joints and flexion of their middle joints. All the fingers extend well for practical purposes, but their flexion is limited to only one-half normal range of motion as all of the long flexor tendons are attached at the wrist. All the fingers are without voluntary lateral motion spreading 3½ inches in the left hand compared to 5½ in the right.

He grasps only three or four of the examiner's fingers very weakly, and is unable to hold two or one at all.

Anesthesia to light touch and pinprick is present over the ulnar third of the hand, all of the little finger, and half of the ring, including the dorsum.

A curved keloid scar 2½ inches in length is present on the volar ulnar aspect of the wrist 1¼ inches above the distal flexion crease of the wrist. There is an open wound with only slight drainage in the center of this scar

Conclusion The ulnar nerve, its posterior branch, and several long flexor tendons were severed at the wrist. Primary repair was complicated by subsequent infection and drainage

Secondary repair of the ulnar nerve and damaged flexor tendons, which is necessary, should be delayed four months after complete healing.

He is at present disabled from work.

Short Report of Injured Nerves and Tendons

Case No April 12, 1943
Emp
Inj E C. Age 19
Date of Inj October 7, 1942

Accident On October 7, 1942, he laid the palm of his left hand on a circular knife used for cutting sardines, making a transverse laceration across the palm. The wound was operated upon at once by Dr ———, who reported that he sutured the tendons, and that all tendons and nerves were cut with the exception of those to the index finger Healing was apparently prompt, though the patient states there was slight drainage. Since then he has had some contrast baths and physiotherapy

Present Complaint He states that the ring finger and half of the little finger are numb, and that he cannot grip well because of weakness and of inability to flex his fingers completely He complains of a tight feeling in the palm.

Examination In the left upper extremity the thumb, wrist, and all proximal are normal.

All fingers extend completely with the exception of the little finger, which lacks 25° in its middle joint and 24° in its proximal joint either voluntarily or passively

Of flexing to the distal crease in the palm the fingers lack as follows

Index	1¼ inches voluntarily and 0 passively
Long	1⅓ inches voluntarily and 0 passively
Ring	1¼ inches voluntarily and 0 passively
Little	2 inches voluntarily and 0 passively

This shows that the limitation of flexion is due not to the joints but to the flexor tendons

He feels light touch and pinprick throughout the hand with the exception of the whole of the volar aspect of the ring finger and the radial half of the little finger Tinel's sign is present in the scar opposite the two nerves that have been severed

Voluntary flexion of the individual finger joints is shown in the following table

	Proximal	*Middle*	*Distal*
Index	85	68	22
Long	83	64	27
Ring	85	90	27
Little.	70	45	14

The 70° of flexion of the proximal joint of the little finger is very weak, showing that it is done by the intrinsic muscles only The little finger has only a trace of flexion in its middle joint and no voluntary flexion in its distal joint. The tendons of the other three fingers are all functioning to some degree, though not completely

He grips 10 kg with this hand compared to 35 kg with the right. He is right handed.

Conclusion The left hand has been seriously injured. Fortunately Dr ——— sutured the tendons promptly Those to the index, long, and ring fingers are functioning fairly well, though limited by scar tissue. That to the little finger is not functioning Two nerves in the palm have been severed, accounting for the anesthesia. It is advisable to attempt to repair the hand surgically

SAMPLE HISTORY OF EXTENSIVE INJURY
(CASE IN FIG. 300)

Case No April 16, 1941
Emp
Inj H. D F Age 40
Date of Inj July 3, 1940

Accident On July 3, 1940, while working as a lineman transferring wires on a power pole, his foot slipped and in grasping for support he contacted live wires with both hands, receiving 2,300 volts through his body He lost consciousness and slumped in his safety belt, thus breaking the contact He regained consciousness while still on the pole, but experienced considerable difficulty in breathing and raised frothy, bloody sputum

He was taken by ambulance to the ——— Hospital in Ventura, California, where he remained for four months under the care of Dr ——— The patient states that treatment consisted of compresses and the removal of slough as it became loosened. When he left the hospital the right hand and wrist were completely healed, and the left hand was healed except for an area at the base of the thumb which drained long but has now almost healed.

At present he complains of complete loss of function of both hands and recurrent colds accompanied by a chronic cough.

He is left handed

Examination (April 14, 1941) Both upper extremities appear much the same, as their respective injuries are almost identical The thumb and index finger are the only digits intact in either hand, and both wrists are in moderate flexion contracture due to loss of soft parts on their volar surfaces. Slight disuse atrophy of the muscles of both extremities is apparent. A detailed examination of each extremity follows

In the left upper extremity all motions of the shoulder and elbow are to normal degree. On the volar surface of the elbow there is a slightly oblique keloid scar measuring 2 x ½ inch Pronation and supination are practically complete, lacking 10 and 15°, respectively

The wrist is in flexion contracture lacking 15° voluntarily and passively of the straight line. The contracture is due to scar on the volar surface of the wrist as a result of

extensive loss of soft parts from the burn, all of the flexor tendons and the median and ulnar nerves at this site having sloughed away The tendons of all the extensor muscles of the wrist and digits and the long abductor of the thumb are present and working, and the skin on the dorsum of the hand and wrist is in good condition The carpal flexors on the volar surface of the wrist are apparently pulling through scar Palmar flexion of the wrist is to 65° voluntarily and 70° passively There are 10° each of voluntary ulnar and radial flexion

The dense scar at the wrist continues into the palm, extending to the thumb and the stumps of the long, ring, and little fingers The thumb web is obliterated, the thumb being bound to the hand by scar contracture. Approximately one half of the soft tissues of the thumb has been lost, and the remaining skin is tight and poor in nutrition. On the volar surface of the thumb opposite the middle segment is a small open wound ⅛ inch in diameter The wound appears to involve only the surface and should soon heal The adductor muscles of the thumb and all thenar muscles are either lost or not working, and there is no action of the long flexor tendon of the thumb which is probably lost by slough within the thumb as well as at the wrist. The distal joint of the thumb is ankylosed in extension, and the proximal joint is held in 25° of flexion from which point there are about 10 or 15° of passive motion. The long abductor and the long and short extensor tendons of the thumb impart slight motion so that the amplitude as measured at the tip is one inch voluntarily

The index finger is intact, but its distal two joints are held in flexion contracture to the extent of 47° for each joint. There is no voluntary motion, but a trace of passive motion is present in these two joints. The proximal joint of the finger has no voluntary flexion but passive flexion is to 70° Neither the long flexor nor the interosseus tendons are working but the long extensor tendon functions, bringing the joint to the straight line The index finger deviates 25° ulnarward at its proximal joint

The long and little fingers are amputated through their middle joints. The stump of each is conical, and the skin is thin and drawn tight by scar The tip of the long finger stump moves ¼ inch voluntarily and that of the little finger stump ⅛ inch voluntarily The ring finger has been amputated through its proximal joint and the stump is covered by dorsal skin The long extensor tendons of the long, ring and little fingers are intact and work slightly

The entire volar surface of the hand and fingers is anesthetic to light touch and pin prick, and all intrinsic muscles of the hand are paralyzed due to the ulnar and median nerves being destroyed at the wrist and probably also in the palm and digits by electricity Sensation on the dorsum of the hand which is supplied by the radial nerve and the dorsal cutaneous branch of the ulnar nerve, is intact. There are two soft well healed scars, one measuring ¾ x ½ inch and the other ¾ x ¼ inch, on the dorsum of the wrist, but these do not bother

The left hand is practically useless, the only action being a weak pinch between the thumb and index finger by his long extensor of the thumb

Examination of the right upper extremity shows slight limitation of function of the shoulder which, he states, has persisted since his injury On raising the right arm in the lateral plane it fails the vertical by 60° voluntarily and passively, and in the anterior plane by 45° voluntarily and 30° passively At the extremes of both voluntary and passive motion pain in and about the shoulder joint is experienced External rotation is limited approximately one-half compared to the left, but internal rotation is practically complete, the dorsum of the hand reaching the sacrum.

The elbow flexes and extends completely Rotation of the forearm is limited volun

tarily and passively, supination being to 45° and pronation to 30° beyond the midposition

The wrist, as on the left, is held in mild flexion contracture lacking 10° voluntarily and 5° passively of reaching the straight line The flexion contracture in this instance is again due to extensive loss of soft parts on the volar surface of the wrist with subsequent scar contracture. The wrist palmar flexes to 65° voluntarily and 75° passively Ulnar flexion and radial flexion are each to 10° voluntarily

The thumb is intact, but the thumb web is so contracted that the thumb itself is sealed to the palm of the hand and a scar tissue web extends almost to the distal joint. There is no action of any of the thenar muscles nor of the adductor muscle of the thumb The long flexor tendon of the thumb has sloughed at the wrist. The long and short extensor tendons and the abductor tendon are intact and working slightly The distal joint of the thumb lacks 45° voluntarily and passively of reaching the straight line on extension, and passive flexion is to 75° The proximal joint of the thumb lacks 30° voluntarily and passively of reaching the straight line, and passively flexes to 35°

The index finger is intact, but its distal two joints are in flexion contracture, the middle joint being flexed to 93° and the distal joint to 18° No voluntary motion and only slight passive motion is present in these two joints. There is no voluntary flexion of the proximal joint, but passive flexion is to 40° The proximal joint extends voluntarily to the straight line by action of the long extensor tendons

The long and little fingers have been amputated through their proximal joints and the ring finger through its metacarpal just proximal to the head. The stumps of all three metacarpals are covered by fairly good dorsal skin.

The volar surfaces of the palm and fingers are anesthetic to light touch and pin prick and the intrinsic muscles of the hand are paralyzed Thus the median and ulnar nerves have been damaged much the same as on the left Sensation on the dorsum of the hand is intact, the dorsal cutaneous branch of the ulnar nerve and the radial nerve functioning

X rays of both hands were taken for purposes of record and also a single chest plate

Conclusion The disability in both hands is total for all practical purposes, and the nature of the disability in each is much the same due to the symmetry of the electric burns In both extremities all flexor tendons and the median and ulnar nerves have sloughed at the wrist, and the resulting scar caused flexion contracture The long ring, and little fingers of the right hand are missing, and in the left hand the ring finger is missing and the long and little fingers are amputated through their middle joints but have poor stumps Both thumbs are functionless due to loss of their flexor tendons, contracture of the thumb web, and absence of sensation Both index fingers work slightly in their proximal joints, but their distal two joints are held in rigid flexion contracture.

Treatment should be directed toward giving him some degree of pincer action between the thumb and index finger in each hand and relief of the flexion contracture at the wrist. It is first necessary to get rid of all scar and poor skin, replacing the same by good full thickness skin and subcutaneous fat by means of the pedicle method. At a later date the necessary tendon and bone work can be done, but it is doubtful whether repair of the nerves will be possible since electrical burns are apt to destroy the nerves for a great length. The substitution of good skin for the extensive tight contracting cicatrix which makes each hand hidebound will result in great improvement of the nutrition of the hand After this skin is in place, new tendons can be placed for the thumb and index finger, and by

osteotomy the right thumb can be placed in a position of function

FINAL REPORT ON CASE IN FIG 281

Case No November 3, 1938
Emp
Inj J C. D Age 32
Date of Inj December 27, 1935

It is now nearly three years since the original infection in the right upper extremity involving the wrist, hand, and fingers, eight months since the tendon grafts were placed in the right hand, and nearly four months since the last operation which was an amputation of the distal segment of the little finger

For the past three months he has been working, doing light work and driving a motorcycle. He holds a wrench, shifts gears, holds firmly objects ranging in size from a pencil to the examiner's hand. He uses a hammer but not firmly when pounding with it.

Examination of the right upper extremity shows all proximal to the wrist to be normal with the exception of pronation of the forearm, which is limited one-half

The wrist is ankylosed in 25° of dorsi flexion and 15° of ulnar flexion, which is a good position of function.

The thumb lies over the palm in a semi opposed position and functions well, its tip touching all segments of the index, long, and ring fingers and the end of the little finger It can touch the radial side of the palm, and spreads from the base of the index finger two inches It opposes in front of the base of the long finger two inches, and the angle of the nail with the palm is 70° In extension the tip of the thumb lacks two inches voluntarily and 1¾ inches passively as compared to the left. The proximal joint extends completely passively, but fails by 15° voluntarily of extending to a straight line. The distal joint of the thumb lacks 30° voluntarily and 20° passively of extending to a straight line. Flexion and adduction lacks ¾ inch voluntarily and 0 passively, and of touching the base of the palm at the base of the little finger Flexion of the individual joints of the thumb is as follows

Proximal	45 voluntarily and 50	passively
Distal	60 voluntarily and 70	passively

All the fingers are held in a semiflexed position and there is a good range of voluntary motion in all of their joints.

The distal segment of the little finger has been amputated. The stump is well healed, well padded, and nontender

The fingers lack of extending to a straight line as measured at their tips as follows

Index	1¾ inches voluntarily and 1 passively
Long	1¾ inches voluntarily and 1¼ passively
Ring	2½ inches voluntarily and 1¾ passively
Little	amputated and middle joint in flexion

Lack of extension of the individual joints of the fingers measured in degrees is as follows

	Proximal Joint		*Middle Joint*		*Distal Joint*	
	Vol.	*Pass*	*Vol.*	*Pass*	*Vol*	*Pass*
Index	10	0	25	15	18	4
Long	0	0	25	18	30	22
Ring	15	0	25	18	32	18
Little	25	0	70	70	amputation	

Of flexing to the distal crease in the palm the tips of the fingers lack as follows

Index	1½ inches voluntarily and 0	passively
Long	1 inch voluntarily and 0	passively
Ring.	¾ inch voluntarily and 0	passively
Little.	¾ inch voluntarily and ¾	passively

Flexion of the individual joints of the fingers as measured in degrees is as follows

	Proximal Joint		*Middle Joint*		*Distal Joint*	
	Vol	*Pass*	*Vol*	*Pass*	*Vol*	*Pass*
Index	55	80	80	105	55	75
Long	45	45	90	100	70	80
Ring	60	70	90	100	70	80
Little	70	80	80	90	amputation	

He now grips in an average of three trials 10 kg with the right hand compared to 46 with the left.

All the finger joints are limber The

amplitude of voluntary motion in the thumb is 2 inches, index finger 2¾ inches, long 4 inches, ring 5 inches, and little 2 inches The nutrition of the hand is good. The hand can be opened for a grasp of 3½ inches.

Conclusion The function of the right hand has improved considerably and it is now useful to him He is able to hold a wrench firmly, shift gears, use a hammer, ride a motorcycle, and hold a pencil firmly between thumb and fingers

He should continue light work The motions of the digits though limited are in the most functional range, so the hand is very useful to him Permanent disability rating can be made at this time. Enclosed are the completed blanks.

4

Reconstruction of the Hand

GENERAL CONSIDERATIONS

The manual worker from the nature of his work injures his hand Of the many accidents in industry over a third of them are to hands. Many result in permanent disability so there are in every large city thousands of crippled hands in need of repair If a worker is entirely dependent on manual labor for his livelihood his earning power is seriously impaired when his most valued member is crippled

The main function of the upper extremity is to place and control the hand It is the hand which does the work and is the important part of the arm. A prosthesis is a poor substitute for a hand and even with the best prosthesis an arm without a hand is of quite limited use Though, for a hand, the support of an arm is essential, the main value of the upper extremity lies in the hand This point of view is of direct and major importance when the nerves of the arm share in the injury Rowley Bristow went so far as to say, "The surgery of the upper extremity is the surgery of the hand.'

When we consider what a wonderfully perfected piece of mechanism the hand is, it is not surprising that successful reconstruction of it by surgery is unusual Let us think of the hand as a marvelously functioning piece of live machinery and regard it with due respect. Though its tissues are tough and compact, its tendons, tendon sheaths pulleys, joint surfaces, and flexible joint capsules all glide on each other so easily and smoothly that there is little in the refinement of motion that the hand cannot do If infection or trauma insults these perfected parts, a tissue reaction will occur, which will bind the gliding surfaces together, thicken and stiffen the joint capsules, congeal the tissues of the finger, and strangulate the nerves and vessels, and loss of function will result.

Hands that come for repair range from those with but a simple severance of a nerve or tendon to those with extensive crippling, in which all of the structures have been damaged The ravages of infection have left the tissues solidly congealed by cicatricial tissue, joints have stiffened in nonfunctioning positions, flexion contractures are present, and great lengths of tendons and nerves may have sloughed and been reduced to scar tissue. Thus, our repairs are *not limited to nerves and tendons, but must* include all tissues

Surgeons avoid these cases because, unless done with a special technic, the results are disappointing, and because the work is so tedious and confining. The operations are time consuming and the office work entailed takes much time Most cases come under industrial compensation laws and require first an extensive examination, recording accurate data and measurements, and then postoperatively hours spent in periodically reexamining and rendering progress reports for a year or more.

To diagnose and reconstruct a crippled hand we should have intimate knowledge of the anatomy, mechanics, and physiology of the normal hand Knowing the normal, whatever pathology exists in the injured hand will be clearly evident.

In the skin, the creases and areas of redundancy conform with the movement The joints from shoulder to fingertips each have their range of motion, which allows the hand and limb as a whole to move into almost any desired position There is a nicely adjusted muscle balance between the long extensors, long flexors, and the intrinsic muscles in the hand, which determines the posture of the hand at rest, and on which depends the use of the hand Any imbalance is readily noticeable

The mechanics of the joints and tendons, the carpal and metacarpal arches, the angles of approach of tendons at each joint, restraining pulleys, the tendon sheaths and all are remarkably adjusted, so the hand and its digits, working in relation to each other, can fulfill the endless functions they perform. Every tissue in the hand is perfectly specialized for its purpose—the skin, nerves, joints, bones, muscles, and tendons —in such complexity and perfection that adequate conception and regard for the normal will influence whether the surgery wrecks or reconstructs Success in repair requires for a hand crippled by injury the correlation of plastic, neuro, and orthopedic surgery, because injuries affect every tissue in the limb irrespective of our medical specialties The hand surgeon must be versatile in all three

For a viewpoint of attack, let us consider the skin as the covering, the bones the scaffolding, the joints the hinges, the muscles the motors, the tendons the ropes, and the nerves the wiring Our problem is composite, as it includes all of these, it deals with deformities, disturbed mechanics, disturbed nutrition, paralysis, anesthesia, trophic and vasomotor conditions, contractures, cicatrices, and defects of all tissues The same tissues are found in both extremities The problem in the lower extremity is largely to give stability, and that in the upper is to give useful motion.

We should weigh well the amount of improvement we expect to accomplish and should avoid undertaking a surgical reconstruction just because it is possible to do

Operation is contraindicated unless the whole ordeal of repair is well justified by the improvement to be gained when viewed from the standpoint of the patient, the insurance company concerned, and the surgeon None of these three will be happy if a long ordeal at great expense has been endured, and the limb is only a little better

We should aim to give the patient sensation, position and the function of opening and closing the hand for grasp He should be given placement of the hand by the arm and as much strength and refinement of motion as possible

Individual reaction to reconstructive surgery of the hand varies greatly Some hands overheal with keloid formation and deep cicatrization resulting in binding adhesions, contractures, and stiff joints, while others remain limber The joints of some persons who have a high cicatricial index, often the thin and arthritic, sometimes the fat, and those over the age of 50 or those who age sooner will stiffen on slight surgical provocation. Ample material should be available to fill in the defects of each tissue The state of nutrition of a limb is all important in the final result.

Throughout our reconstruction we should keep in mind that the hand should be brought into the position of function and should never lose this position. We should keep the hand always moving or it will *stiffen. If the hand is left long in a cast or* in a rigid splint, or long in a splint with joints on a strain the joints and all tissues *will stiffen.* Hands are peculiar in that to thrive and avoid stiffening they need function. The natural state of a hand, and the only one in which it will thrive, is that of *motion.*

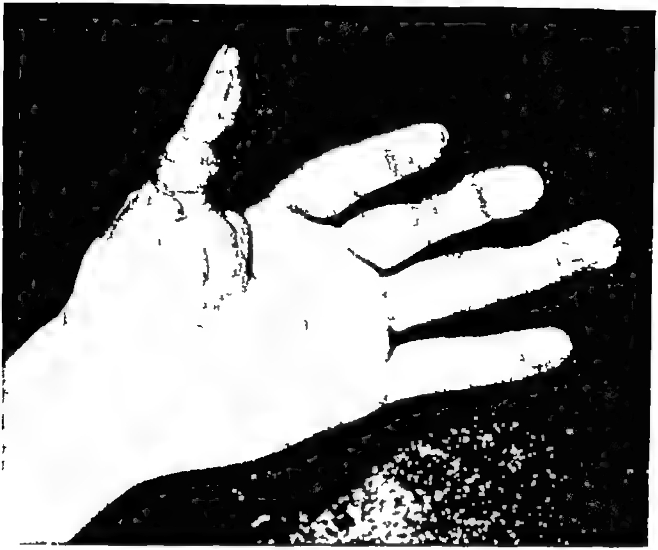


FIG. 59 Beware of an annular scar! Reconstruction of such a digit is not often successful.

In hand reconstruction much can be done if one will give the time, care, and patience This is no work for the novice The usual surgical procedure is too rough, so it is necessary in this work to use as nearly as possible an atraumatic technic. In hand reconstruction certain main principles must be kept in mind. The rest depends on a host of tiny but important details.

In a large hospital hand repair should be a separate service under those trained in the surgery of this region, thus excluding the necessity of referring the hand patient in turn to the plastic orthopedic and neurosurgical departments. At the broad shoulder the three specialists can work separately, but at the end of the tapering limb in that little pound of tissue, the three types of surgery are so bound together that there is one composite problem which should be attended to by one man. Hand surgery is not a tissue specialty, like the other three, but an anatomic or regional one like that of the eye and ear The hand surgeon should choose between free and pedicle skin grafts according to the tissues beneath, and should place the borders of his pedicles with the conception of a moving hand, that is, without contracting keloid scars coinciding with lines of push and pull, and he should make his pedicles aseptic to avoid stiffness At dissection, valuable observations of the under structures can be recorded for the whole repair problem Some other structures like nerves and deep flexion contractures, can be repaired at the time of the pedicle. If he operates to repair a nerve, he can repair many other deep structures at the same time, instead of

having to make two extensive dissections Often on uncovering a forearm and hand, the findings cause one to change the plan of procedure from nerve repair to tendon transfer or arthrodesis, or a bone operation with plastic swinging of flaps included It is all one composite problem, and the full responsibility to the patient should be held by one surgeon The mechanical unit of the hand, that is of bone joint and muscle action, is from the elbow down The dynamic control of the hand starts at the opposite cerebral cortex. The main function of the whole arm is to place the hand where it can work

MAIN PRINCIPLES

Plan. A definite plan of procedure should be thought out, giving the chronologic sequence and serial order of each of the operative procedures and courses of treatment. Consideration is given to the time schedule the patient can arrange and the expense he can bear

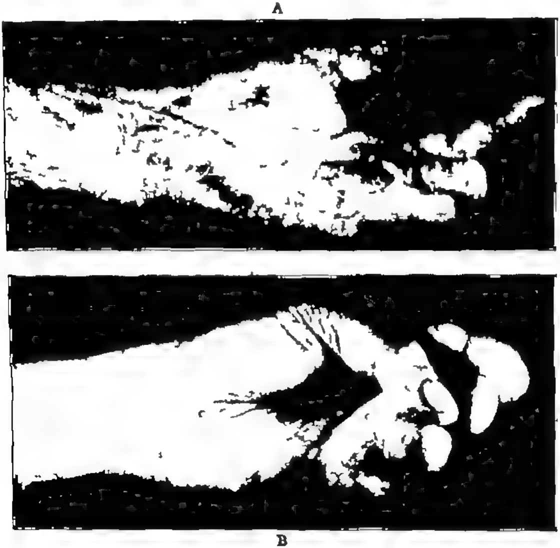


FIG 60 Case A. T Showing the great improvement in the nutrition of the hand produced by dissecting out all of the deep cicatricial tissue from within the hand This octopus-like internal scar bound blood lymph vessels, and nerves causing the poor nutrition shown in (A)

The hand had been almost severed by a buzz saw following which infection developed. The tendons and nerves sloughed out, robbing the hand of all motion and sensation, except that supplied by the radial nerve.

Restoration of good function was accomplished by repair of the nerves and tendons, but the point exemplified here is the improvement in nutrition as shown in (B) due mainly to excision of the deep cicatrix. (Courtesy Jour Bone and Joint Surg)

A B C D

FIG. 62 Case R. L. A year previously hand was caught up to the wrist between two steel rollers, causing multiple fractures, exposing the flexor tendons, and tearing away the thenar muscles. The wound healed in six months and physiotherapy was used for five months.

The hand was completely disabled. He could not grasp an object his only way of holding one was by pressing it between his hand and something else. The wrist was flexed out of use and the proximal finger joints were extended out of use.

A broad keloid extended from the distal end of the palm up the forearm for six inches, holding the wrist in flexion and the thumb in adduction. The finger joints were quite stiff The thumb lacked an inch of touching any finger In (A) and (B) is shown the extent of flexion and extension.

Operation After bringing the proximal finger joints into flexion by the slow traction method, *the scar tissue was dissected from the palm and forearm, and from between the tendons, nerves,* and blood vessels, which were matted solidly together A gap of 1¼ inches which was found between the ends of the nerve to the third cleft was bridged by a free graft from the sural nerve. The flexor tendons freed from scar were made to pull the fingers into flexion. The wrist was put into extension and the thumb in abduction. The large skin defect was covered by a tubular pedicle from the chest. (C) and (D) taken four months later show fairly good extension and flexion of the hand. The thumb touched every finger Sensation returned in the third cleft. He returned to his work. (Courtesy Surg., Gynec., and Obstet., 39 254 No 9 1924)

joint. The former demands postoperative immobilization, and the latter mobilization.

Tourniquet. In all dissections of the hand it is essential, in order to protect anatomic structures, especially nerves, to dissect with accuracy and to avoid the trauma of sponging, to operate under the ischemia of a tourniquet, such as a blood-pressure band. Prolonged ischemia will provoke a generalized tissue reaction, which results in a degree of firm induration of the parts, one hour is safe, two hours give some reaction and three and one-half hours, in one case gave transient paralysis. The pneumatic blood-pressure band, applied for a reasonable time will not cause paralysis, whereas an Esmarch bandage used as a tourniquet often does Local anesthesia especially with adrenalin content, is best avoided, as it lowers the resistance of the tissues The tissues must have maximum vitality for healing Block or general anesthesia is preferable.

Other Considerations. After trauma, infection, or operation the tissues are usually densely indurated. A second operation on such tissues will result in the summation of scar tissue and so had best be delayed a few months. The final result is not obtained until after the softening-up process has taken place. This often requires a year

I have been disappointed with the results of passive physiotherapy as usually practiced, and have far more faith in certain exercises actual use of the member, occupational therapy, and last but not least the time factor

For many reconstructions, special splints will be required They are usually of metal and can be sterilized by boiling for application at the end of the operation They frequently must be made to fit the case and for that reason sometimes must be made by the surgeon himself

It is most important for later reference to make a complete record of a case before the repair is attempted, as detailed in Chapter 3 By establishing a record of the exact condition before repair, the degree of improvement in the final result can be ascertained.

Latent Infection. Before reconstructing a hand a delay of at least four months following the final healing of the original wound should be allowed, to lessen the danger of latent infection and also for the tissues to become more mobile. This interval may be shortened if the wound healed per primam and no infection occurred. Thus, often a repair can be done in a month following final healing If osteomyelitis has been present, the delay should be at least six months or longer Usually we can operate near the site of an old infection without inciting a flare up, but danger is encountered when we operate at the site itself, especially if we are dealing with bony tissue. A real advantage of operating within two months of injury is that we can usually draw a severed tendon together and suture it. Beyond that time, the muscle will be so shortened that tendon grafting may be necessary

The foregoing paragraph was based on pre-penicillin days With penicillin given pre- and postoperatively, the operation can be done a month after the infection has healed and in two weeks after healing per primam. After osteomyelitis, perhaps two months would be reasonable. Greater caution is necessary following a long deep-seated bone infection than a short one. The bacteria present may not be penicillin sensitive.

A pedicle graft can be applied using penicillin soon after injury or infection, as it does not involve the infected area of bone or deep cicatrix Another operation can be done as soon as the induration has lessened, which may be in one or two months

Order of Procedures The following is usually the order of procedure in reconstructing

First, positions of function should be gained, then a good covering of skin and subcutaneous fat established Nerves should be repaired before tendons, and also bones and joints before tendons Tissues should be given time to soften between operations, or there will be a summation of scar tissue A year or more should elapse before the case is given a permanent disability rating. Often much improvement of motion takes place even after the eighth month, and some continues over several years. Motor nerves severed anywhere from hand to cord should be given priority in early repair The sooner done, the better will be the regeneration and the less the atrophy

OPERATIVE TECHNIC

Cleansing Skin

Preoperative cleansing of the skin the night before should be thorough, using soap and plenty of water and scrubbing all the scales off the skin with a soft brush or gauze. An hour of preliminary soaking in wet, warm compress greatly aids in this Skin should be scrubbed down to the live tissue The presence of epidermal scales should always be made known to the nurse in charge of preparation Just before operating a final soap and water cleansing is worthwhile. Good old fashioned scrubbing and rinsing may alone be sufficient, but in addition, in order to be doubly safe, I prefer to paint the skin with either half strength tincture of iodine or 1 1,000 solution of merthiolate in alcohol

Draping and Lighting

It is important to so place the operating table that the part of the hand to be oper

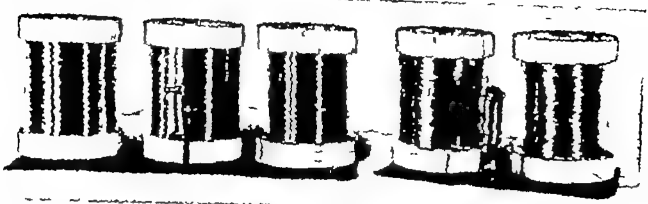


FIG 63B Convenient metal stands for spools of stainless steel wire. The wires are easy of delivery and after each cutting to keep them from tangling are pressed into the sides of wire springs on vertical rods.

incision is made, following the distal crease and then turning proximally in the immobile heel of the palm to the center just beyond the wrist This incision cuts through the palmar aponeurosis and as the skin and aponeurosis are dissected off from the blood vessels and nerves, small hooked retractors hold them out of the line of vision Dissecting through normal tissue is an easy pastime, but not so through the cicatrix left by the storm of infection Here, one usually locates the nerves and tendons in tissues farther proximal or distal where the cicatrix is less dense, and then follows them through the scar bound mass. In dissecting with the scalpel down nerves, tendons, or vessels a trick is to use a sweeping, feathering stroke, with the edge of the scalpel always directed away from the structure we do not wish to cut. Both the tissue being preserved and the tissue being cut from it should be held tense This feather stroke of the knife applies throughout our dissection wherever we wish to avoid cutting the structure we are uncovering

Another useful instrument for dissecting out cleavage planes, nerves, vessels, or tendons is the old dissecting probe by which we lift connective tissue away from these structures In following a very narrow nerve plastic scissors are especially useful. These are double-pointed, curved on the flat, and kept well sharpened. The point is repeatedly thrust along the nerve and then spread It is better to dissect nerves from above downward, so as to preserve their branches In excising deep cicatrix, which procedure should accompany most of our reconstructive work, we should start at one side and go systematically across the whole area, excising the cicatrix en bloc as we do for cancer, but preserving all of the essential structures, such as nerves, vessels, ligaments, and tendons. If thus cicatrix is left it breeds new cicatrix. We should excise all if possible, so that our wound is lined with vascular, normal-appearing tissue.

Procedures. In operating, the order followed is usually to make most of the skin incisions early and to the full distance needed Then we dissect out the nerves and tendons and excise the deep cicatrix. Some muscle belly is found available to move each tendon, and by tendon graft or transfer we connect each tendon to some muscle so as to restore where possible extension and flexion to wrist and all of the digits, opposition and adduction to the thumb, curvature to the arches, and proper muscle balance throughout. Where pulleys, ligamentous bands or tendon sheaths must be cut, they are cut through one side and later repaired if necessary Skin margins, tendons, muscles, nerves, or joints are really freed, so that their complete movement is no longer hampered. We should actually accomplish this, not merely in effectively imitate the motions of doing it.

Tendons are repaired first as they are tougher, and nerves are repaired at the end because they have to be protected from re breaking and often must be sutured in awkward positions which must be main tained until the skin is closed and the limb immobilized

If a rough surface of ligament or bone underlies a tendon we should, to prevent it from adhering, interpose a sheet of tissue which will separate it from the tendon and allow gliding Whether this material be loose paratenon fat from over fascia lata or over triceps tendon, or thin, deep fascia from forearm or thigh, there is an easy way of interposing it and holding it in place. First it is laid out on a clean towel and mosquito hemostats are attached to its cor ners. Number 000 catgut on straight or curved needles is then thrust through its borders and tied The needles attached to one side of the membrane are then passed between the tendon and the bone and on out through the skin to the opposite side of the finger or limb Here the strands are tied to each other outside the skin Those catgut strands attached to the near edge are then brought out through the near skin and also tied outside The catgut may be placed continuously, penetrating back and forth between the inside and outside of the limb The interposed membrane will then be held taut in place between the tendon and the tissues which we desire to prevent from adhering

If on closing it is found that the skin cannot be sutured without undue tension, as shown by its blanched appearance, some plastic maneuver is resorted to, so that by eliminating tension the skin will show good pink color throughout. Sometimes, to accomplish this we must make a parallel incision, undermine the skin, and allow the edges to gap sufficiently for the closure. The denuded tissue thus exposed is covered in by skin grafting

At the beginning of the operation and throughout the time that the tourniquet is maintained we should work very rapidly By conserving motions, making each one count, and keeping our mind on the main issues, our work can be done rapidly and accurately and still without detrimental haste. If we do not develop speed it will be impossible to get through an extensive operation There is usually time to com plete all dissection and quite a little of the repair work before the flood gates of blood are reopened The wounds are then held firmly with gauze for a few minutes until clots form in the tiny vessels. Sponging should be extremely gentle and without any side motion which would express these clots, causing rebleeding Elevating the limb at this stage is helpful. Then the larger bleed ers, omitting the surrounding tissues, are accurately caught with mosquito hemostats and tied with No 00000 or 000 catgut. This is absorbed in a few days leaving the tissue normal, but silk leaves a permanent capsule of scar Gross repair of tendons and nerves can then be done without the tourniquet, but if this is found to be diffi cult, the limb can be rewound after ten minutes and the tourniquet again inflated

Hemostasis Hematoma or postopera tive bleeding resulting in a blood clot under the skin which separates the structures and later leads to drainage and adhesions, a complication we should always keep in mind and use the following methods to pre vent

Hemostasis at the end of the operation should be as complete as possible. If, after this, oozing of blood is still present, there should be placed between the sutures multi ple drains of rubber tubing not over 3 mm in diameter, with a small safety pin in each These drains should not overlie repaired parts and should be removed on the follow ing day, or if drainage is excessive on the second day It may be impossible to stop all oozing of blood in which case thrombin helps Also, one may rewind the limb to force the blood out, pumping up the tourni quet until a voluminous waste or fluff dress-

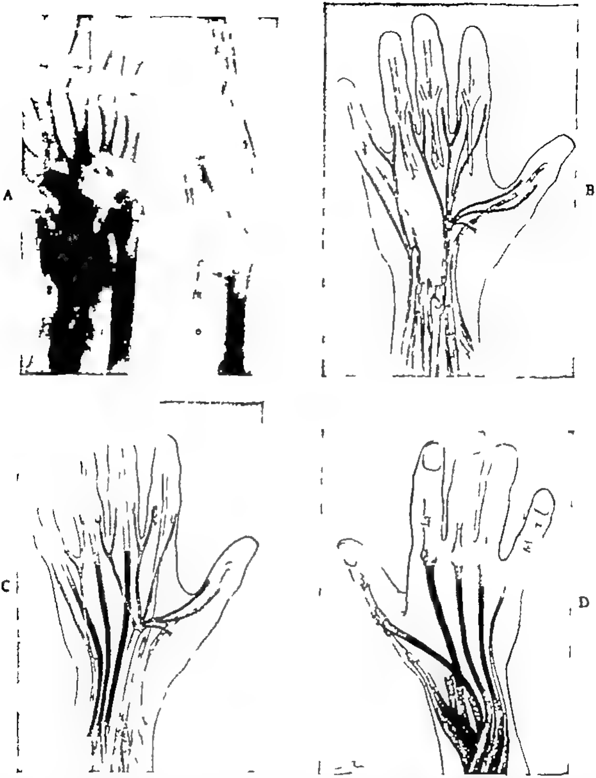


FIG. 64 Case C. B A year previously while duck hunting his shotgun discharged through his right carpus. In (A) is shown the result. The joints are stiffened in nonfunctioning positions and there is no movement of supination. The hand and wrist are completely without motion, there is no sensation in the area supplied by the median nerve a wide cicatrix with a discharging sinus covers the dorsum of the wrist, and a smaller one is in front. The hand is completely useless.

Operation (in several stages)

After excising the sinus and diseased carpus, good skin was replaced over the wrist by a pedicle graft, as shown in (H), and joints were drawn into functioning positions.

The cicatrix was excised from the hand and forearm both ventrally and dorsally In (B) is shown the condition of the tendons and median nerve found in the palmar aspect. The median nerve was sutured, tendons were freed from scar and seven tendon grafts from the long extensors of the toes were placed, as shown in (C) and (D) The distal parts of the sublimus tendons were excised. Capsulotomies were done on the proximal finger joints and a segment was removed from the lower end of the ulna to give pronation and supination. (Courtesy Jour Bone and Joint Surg., 10 1 No 1 1928)

E F G H

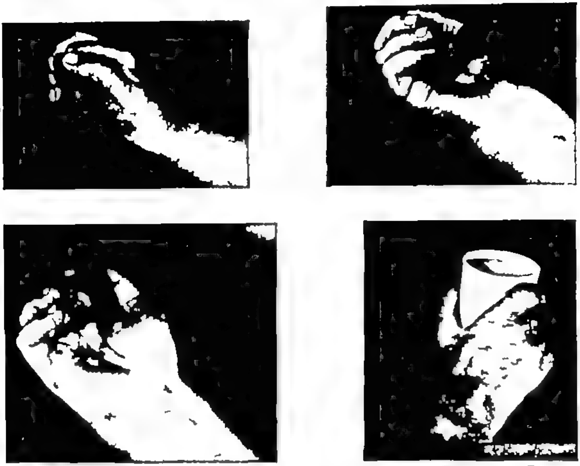


FIG. 64 (*Cont*) Result In (E) (F) (G) and (H) the hand is shown two years later Wrist is in a cock up position and has 10 of motion. He has 125 of pronation and supination and the thenar muscles have been re stored through the nerve suture. Nutrition and good natural sensation are present throughout and he can distinguish by touch in the median area a pencil, knife, a quarter or fifty-cent piece. He can pick up objects from a match to a tumbler and has a spread of three and one half inches between the thumb and index finger He throws a baseball uses plyers, wrench or hammer holds nails writes well with this hand, and does rough labor of riveting and reaming (Courtesy Jour Bone and Joint Surg., 10 1 No 1 1928)

ing is applied, wound around snugly enough by elastic flannelette bandage to check ooz ing, but not so tight as to produce ischemia. A large fluff dressing is less apt to make pressure necrosis than a thin one. To gauge the sympathetic touch in bandaging requires experience. A rubber sponge or sponge rubber incorporated in the bandage fur nishes useful pressure and splinting. After simple operations in which large arteries have not been severed, the tourniquet may be removed after the pressure dressing is in place.

After a long extensive operation of grafts and much exposed tissue, penicillin is good insurance against infection.

Dressings. Postoperatively, the part of the limb operated upon should be immobil ized and the limb kept elevated, because motion and the dependent position cause oozing.

The wrist should be immobilized in flex ion following repair of the flexor tendons but after repair of the extensor tendons the wrist and fingers should be held in dorsi flexion. A slab of plaster of Paris laid on the dorsal or flexor surface of the limb respectively will accomplish this The joints should never be put up under full flexion as this will wreck them Instead, as the plaster sets, the extreme of flexion is eased off a bit to relieve the strain Fingers

should rarely be put up in flexion to prevent flexor tendons from breaking, because the tendons will adhere too far proximally and it will later be difficult to extend the digits. Flexion of the wrist is sufficient to rob the muscles of breaking force After nerve repair, in order to prevent the nerve ends from being pulled apart, it may be necessary to flex various joints. The elbow, wrist, and finger joints can be maintained in flexion by a dorsal plaster-of Paris half circumference splint, and to flex the shoulder it may be necessary to hold the arm across the chest with adhesive plaster

Postoperative. Postoperatively, to lessen swelling, the hand should be kept elevated on pillows considerably higher than the shoulder Massive pressure dressings of waste, fluff and elastic bandage keep down edema and hematoma and act as a temporary splint until the application of plaster when swelling has subsided Twenty four hours after operation the bandages should be loosened and any plaster cast opened to the skin for its full length and spread apart, because by this time swelling will have occurred. The dressings should be immediately reapplied however, to the proper degree of pressure. For this reason, at operation the casts should be bivalved or left open along the top, never made encircling When after bone carpentry, the bones are firmly repaired, it is well to dress by binding a large mass of cotton waste about the hand A nonpadded half cast can be applied after five days. After arthrodesis the skin at the side of the wrist may slough because of the swelling and cast Drains are removed if the discharge of blood is not excessive and there are no signs of hematoma Simple cases leave the hospital the following day, but it is better to keep extensive cases several days This gives them a chance to recover from the effects of the anesthetic and allows general bodily rest which helps healing Freshly operated hands should not be allowed to hang down but should be kept elevated while in bed and in a sling when ambulatory The patient who is undergoing prolonged treatment should be reminded occasionally to elevate his arm vertically lest, due to contracture of the great muscles that lower the arm, he lose the ability to do so

The danger of ischemia should ever be kept in mind, the necrosis or gangrene that follows leads to awkward complications. Tissue, to remain alive, must at all times have adequate blood supply Following an operation the tissue must not only remain alive but also must ward off infection and undergo healing, which demands a greater blood supply than normally As mentioned above, too tight dressings or casts cause ischemia and too loose ones hematoma, so the surgeon is between Scylla and Charybdis Eternal vigilance is required to ward off these dire effects Ischemia is seen when skin is sutured under too much tension, and in such a case, of course, ischemia extends to the deep tissues below Elevation and drainage lessen this tension, but extra time spent at operation in relieving it will be well repaid Throughout plastic surgery the ischemia of the overtight pedicle or overstrained tissue is ever ready to spoil our result unless it is ostentatiously guarded against.

Our Limitations. In hand repair, we should recognize our limitations and not hope to make a perfect hand out of a cicatricial wreck. The state of nutrition in the hand and the amount of binding cicatrix throughout is the main factor in the prognosis *The greater the magnitude of the trauma, and the greater the intensity and duration of the infection, the worse will be the material we will have to build upon.* If there are too many unfavorable aspects to repair of a finger, such as annular scar, *injured nerves, joints, tendons, and* skin, it is better to amputate.

EXTENSIVE CASES

To diagnose, measure, record, and photograph properly a badly crippled hand re-

quires an hour, and to reconstruct it may consume a year. It will first be necessary to relieve flexion contractures and replace cicatrices by pedicled grafts. Over a period of weeks joints are placed in positions of function and mobilized. Many operations will be necessary and time must elapse between each for nerves to regenerate and induration to subside. In an atrophic finger we must not repair the tendon or place a tendon graft until after the nerves have been repaired and have had time to regenerate, for if we do our healing will be cicatricial and our graft will degenerate or break. Operations themselves are several hours long and very fatiguing. As long as the tourniquet is on one works under the stress of speed to accomplish as much as possible, including dissection and nerve suture, before the flow of blood obscures one's vision.

To the patient with a mere club for a hand with stiffened joints, no motion, no sensation, and poor nutrition, it means much if we can restore to him even sensation and the ability to grasp. The loss of a leg is small compared to the loss of a hand.

Prognosis

The prognosis depends on several factors. Only by great care on the part of the surgeon and continued attention to the endless number of details involved in this tedious type of work will the reward of having grateful patients be obtained. Success is somewhat dependent also on the part of the patient. If fear of pain is paramount and will power weak, he will not exercise the hand sufficiently or strongly enough to mobilize the tendons. One must take some punishment for the reward of a good result. There are other patients who are prone to form cicatrix and whose joints have an unusual tendency to stiffen. Results in this type fall short of the average. Far better success can be obtained in children than in the aged, though procedures like arthroplasty give poor results in children.

The main factor in prognosis for obtaining movement and sensation by return of tendon, joint, and nerve function is the state of nutrition in the hand and the amount of cicatrix within it. In extreme cases, where the hand has been thoroughly gutted by infection and its contents replaced by cicatrix, its nerves and tendons destroyed, its joints stiffened, and its general nutrition greatly reduced, we should be able to restore to it positions of function of the joints, a useful degree of sensation and the ability to grasp objects and to open the hand from two to five inches. If a finger is only fairly cicatricial, but has flexible joints, one can replace its damaged tendon and probably give it flexion to within one half inch from the palm. If its joints are stiffened beyond repair, less is to be expected. When tissues are in excellent condition, however, the chances are good for restoring considerable useful function, often nearly approaching the normal and to the degree that there is no longer any interference with work.

Tourniquet

General Usage. It is impossible as well as too dangerous to dissect a hand properly without the aid of ischemia from a tourniquet. The hand is exceedingly vascular and is filled with tiny structures that will be injured unless our vision is clear and exact. Without a tourniquet our field is ever covered with blood which is opaque, so instead of progessing with our dissection we will be fumbling, traumatizing the tissues by forever sponging, and the tissues will be crushed by too many hemostats. Could a jeweler repair a watch immersed in ink? In pleasant contrast is our dissection on a limb in which the blood is held back by a tourniquet. It is possible to see every little nerve and vessel or other structures we should not damage and to dissect with accuracy and minimal trauma. At the end of the operation the tourniquet is removed, the wound is held under steady

gauze pressure and elevation for a few minutes, allowing the small vessels to be stopped by clot, and only a few hemostats will then be needed for the larger vessels.

Paralysis has often resulted from using as a tourniquet an Esmarch bandage. Each turn adds to the pressure and when the turns narrowly overlie each other actual nerve crushing may result. Spigel and Lewin found 18 cases in the literature and reported three cases in which some type of tourniquet had been used. Most paralyses were temporary, ending in three to six weeks, but five were permanent. The three examined showed that the paralyses were due to pressure necrosis, cicatricial constriction with nodular neuroma formation. None were from the pneumatic tourniquet. The pneumatic band of a blood-pressure apparatus, however, apparently never causes paralysis, at least not when left on for less than three and one-half hours I have used it many thousand times without mishap The tourniquet can be kept on safely for an hour and a half and even two hours—if longer than that there will be some degree of tissue reaction. It is well to do all of the dissection and much of the repair work before the tourniquet is released, though in extensive cases it is sometimes necessary to do the actual tendon and nerve suturing afterward. After the limb is given a breathing spell of ten minutes, the tourniquet can if necessary be reapplied for another hour and a half A quick way of expressing the blood from a limb is for six hands to grasp it firmly while the pneumatic tourniquet is being pumped, but the ischemia afforded is not quite as complete.

Local and block anesthesia, including that of the brachial plexus, are far more effective when a tourniquet is used. The anesthetic, when placed below the tourniquet, is kept in the tissues and the tourniquet itself, after 20 minutes, furnishes anesthesia. When a regional anesthetic is used, the tourniquet which is not uncomfortable when first applied causes, after 40 minutes, considerable aching in the arm. This lasts for about 15 minutes and then subsides. Patients without much stamina are annoyed by this, but others find the ordeal slight. The painful stage can be tided over by a hypodermic of morphine and soothing words of comfort from a nurse. Aching of the arm is not felt in brachial plexus anesthesia.

Application. First place the cuff of a blood-pressure band or pneumatic tourniquet encircling the limb near the shoulder, not tight, with the tubes proximal. The former should be reënforced with a bandage, because under inflation the bag may bulge irregularly Not until the limb is completely sterilized and draped, is it rendered ischemic by winding it with a bandage. After laying a sterile towel on the limb, the blood is expressed by winding from finger tips to above with a sterile rubber Esmarch Ace or other elastic bandage. If one of these is not available, even gauze will do Tourniquet time is precious so the limb is not wound until the last minute before the operation The elastic bandage should be kept sterile lest it be needed again.

The pressure in the bag is raised to 300 mm. of mercury, or in a child to 250, or infant 150 mm , the tubes are clamped with rubber-protected clamps and the Esmarch bandage removed It is necessary to leave a space of at least one inch between the Esmarch bandage and the blood pressure cuff, for if the bandage is wound right up to the cuff, the pressure within the latter will be so lowered on removal of the Esmarch bandage that troublesome bleeding will occur during the operation. A pressure of 300 mm of mercury corresponds to five and one-half pounds, one of 258.5 mm. to five pounds and one of 310 mm. to six pounds. One pound pressure is equivalent to 51 7 mm. of mercury

When it is desired to have the cuff high at the shoulder for work on the upper arm, it can be held so by a strip of bandage placed across the shoulder and around the

chest. Each end is laid under the blood pressure band, brought back over it, and after crossing over that shoulder is passed around the chest again and tied The blood pressure cuff should be applied at first rather loosely to avoid venous congestion in the limb before it is inflated On removing the cuff, it should be placed across the room so the surgeon will be sure it has not been left on the arm, causing awkward bleeding from venous congestion The bag of the cuff should be regularly inspected for leaks by inflating it under water

Better than the blood pressure cuff is the Conn tourniquet made by Goodyear Rubber Co The cuff is flat, does not need bandaging, the gauge is attached, and the cuff may be boiled for use in a sterile field

If applied too loosely, the pressure does not reach the arm, and if it becomes soapy or the strap is put through the wrong slot in the buckle it will release

Tourniquet in Infections The Esmarch bandage should not be used to express the blood from infected hands before applying a tourniquet, for this will express bacteria and their products into the general circulation. In infections, therefore, the blood is emptied from the arm by holding it for several minutes in a vertical position before inflating the pneumatic tourniquet. The inflation should then be done very rapidly so the heart will not get in several beats, forcing more blood into the arm before systolic pressure is reached Therefore, instead of using the bulb of the blood pressure apparatus, which is too slow, the pressure can be raised to 300 mm of mercury with one stroke if we use an ordinary tire pump

Anesthesia

Selection. Selection of the anesthetic depends on how extensive is the case and on the temperament of the patient. Block anesthesia is simpler for the patient and is usually used for short operations General anesthesia is essential for extensive work.

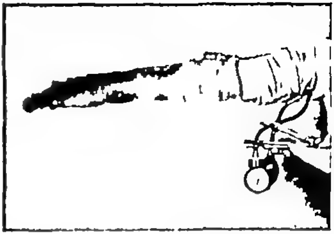


Fig. 65 Tourniquet is essential for all operations on hands. The pneumatic blood-pressure cuff is pumped to 300 mm. Hg after first expressing the blood from the limb by an elastic bandage. The bare zone between the two is essential because the removal of a bandage if wound to the cuff would reduce the pressure in the cuff An Esmarch bandage used for tourniquet may cause paralysis, but the above method does not. *Note* The Esmarch or Ace bandage is not applied until the field is sterile.

In infections, block anesthesia is contraindicated It traumatizes and lowers the resistance of the tissues locally proximal to the infection, thus preparing the field for a sudden metastatic flare-up or spread of the infection to that area. Local anesthesia, if used for infections, should be confined to the line of incision. For all but the simplest infections general anesthesia is preferable.

For minor operations in the office, ethyl chloride, local, block, and brachial plexus anesthesias are used, always in conjunction with a tourniquet. Intravenous sodium evipal or pentothal furnish short general anesthesia when specially needed.

General Anesthesia. A general anesthetic is chosen in all cases of extensive hand repair and in those in which there are multiple regions of the body to be anesthetized. It makes for comfort and ease of operating for the surgeon, unhampered by the various distractions from the conscious patient. It is preferred if the patient is timid, has a low threshold to pain, or is loquacious. Extensive hand cases in which

a new set of tendons and nerves are supplied sometimes drag out for many hours, even to five or seven. In these, it is found that a light ether anesthetic is quite satisfactory Fortunately, in operating on extremities the anesthesia can be very light and postoperative pneumonia which is so common after operations on the trunk, especially near the diaphragm, is practically unknown. Moreover, we do not have in hand work the large veins, which in abdominal surgery are prone to cause lung infarcts.

Following a long ether anesthetic it is advisable for the patient to remain in the hospital at least two days.

Brachial Plexus Anesthesia. In hand operations involving the upper part of the forearm or lower part of the upper arm, satisfactory anesthesia can be obtained by blocking the brachial plexus in preference to the usual blocking of the nerves in the forearm This, when done properly, gives excellent anesthesia, and there is no complaint on the part of the patient of pain in the arm from the tourniquet. The tourniquet improves the anesthesia so that one can if necessary operate for two hours. In the technic of brachial plexus anesthesia certain points are helpful. With the patient lying on his back the arm should be drawn caudalward by another person to make the clavicle uncover the plexus. The needle is introduced three-quarters of an inch above the center of the clavicle and aimed backward, downward, and inward until it strikes the first rib The scalenus anticus muscle is the most prominent in the neck there, and the plexus is just behind it. The subclavian vessels are avoided by first locating them by palpation and also by sucking with the syringe before injecting It is quite important not to prick the dome of the pleura. Death has resulted from this The multiple accidental punctures of the apex of the lung resulted in fatal unrecognized pneumothorax. Therefore, care should be used to prevent this by being guided by the feel of the needle against the first rib Progressing up the first rib feeling like a blind man with his cane, and withdrawing the needle an inch at each stroke, one first feels the inner cord, then the posterior and then the outer They give a cushion like resistance and paresthesia should be elicited at each The head should be straight, for if it is turned away, the plexus rides up on the rib Twenty cc. of two per cent novocain solution with three drops of adrenalin to the ounce is distributed into each of the cords

FIG. 66A. (*Left*) Plaster slab applied after repair of flexor tendons to rob the muscles of strength by keeping the wrist flexed and allowing the fingers to straighten and have some mobility
(*Right*) Plaster slab applied after repair of extensor tendons to hold wrist and proximal finger joints in extension until the tendons have joined.

and some also is injected on slightly withdrawing the needle so that it will be sure to inject into the cone shaped fascial sheath enclosing the plexus Another technic is to enter higher and more median, away from the great vessels, to hit the transverse process of the sixth vertebra and inject all the solution there. The great vessels are pressed away mediad by the finger on the sixth transverse process.

Block Anesthesia. This anesthetic is especially useful for routine work on fairly simple cases where the operation does not last longer than two hours It should be used only on quiet, cooperative patients who have self-control and will not bother the operator because the pneumatic tourniquet toward the end of the first hour is somewhat painful though entirely bearable by the normal individual The worst of the pain lasts only about 15 minutes, and for this an additional hypodermic and a few words of encouragement generally suffice. A preoperative sedative helps considerably, such as sodium amytal 3 gr, at bedtime and 6 gr in the morning two hours before the operation

A tourniquet on the upper arm is used in conjunction with the block anesthesia, and in addition 3 drops of adrenalin per ounce are added to the 2 per cent novocain in all block anesthesias except that of a digit. Adrenalin should never be injected into a digit, because from this gangrene has often resulted, the ischemia which must be removed serially lasts too long A good routine is to block the ulnar nerve at the elbow and the median and radial nerves above the wrist. Anesthesia results in one to five minutes and after working on the hand for a while one can also operate painlessly on the forearm, the tourniquet furnishing the higher anesthesia. To inject the ulnar nerve the arm is held in supination by an assistant with the elbow not quite in full extension and resting on a folded sheet. By palpation the ulnar nerve is trapped between the finger and internal epicondyle. Here it is penetrated with a quick jab by a fine hypodermic needle aimed just distal to the palpating finger When the patient announces that pain runs to the little finger, 2 cc. of the anesthetic are injected in the nerve and about 5 cc. around it.

To inject the median nerve, the arm is steadied by an assistant, with the dorsum of the lower part of the forearm resting on the folded sheet. Two inches above the wrist the fine needle is made to penetrate the skin just radial to the palmaris longus tendon then with a few quick half inch jabs the median nerve is located, as is announced by the patient who feels a pain in the thumb or first three fingers. It is then

FIG. 66B Plaster-of-paris nonpadded cock up splint bivalved to allow for swelling by placing a layer of waxed paper between top and bottom plaster

A rod of plaster crosses through the first cleft along the distal palmar crease, narrow enough to allow opposition of the thumb and right angle flexion of the proximal finger joints.

injected as was the ulnar nerve. The median nerve may be found usually just to the radial side of the palmaris longus, but sometimes under the palmaris longus or as far radial as under the tendon of the flexor carpi radialis.

To inject the radial nerve the sharp edge of the curve of the lower end of the radius is used as the guide. The anesthetic is placed subcutaneously in the deep layer of fat, starting at the edge of the radius two inches above the wrist and extending to the wrist in an ever widening area to reach the various branches. No attempt is made to hit the radial nerve itself.

Injection of the ulnar nerve if awkwardly done has resulted occasionally in postoperative tingling for a few weeks or in breaking the needle.

When the arm is draped for the operation, the border of the sterile sheet which encircles it should be at least two inches above the epicondyle of the humerus to allow *injection of the ulnar nerve*.

Occasionally it is desirable to block the median nerve in the channel under the transverse carpal ligament, or to block the *ulnar nerve as it grooves the inner side of* the pisiform bone. At the latter site, however, one may puncture the blood vessels that accompany the nerve.

The volar *digital* nerves, when anesthesia of a digit is required, can be blocked before their bifurcation at the distal part of the palm. In addition, an infiltration block should be done on the *dorsum of the hand*. Distal to this adrenalin should not be used. The finger can be blocked at its base by 1 cc. of 2 per cent novocain solution near each *volar digital nerve, entering dorsally* where the skin is thin, and another 1 cc. subcutaneously across the dorsum. When the tourniquet is removed this anesthesia *will quickly leave, because of the absence* of adrenalin. Finger blocks are dangerous.

Block anesthesia should not be used for infected hands. It is quite useful in treating *freshly injured hands in an office or* first-aid station, and allows thorough excision and closure of wounds.

Local Anesthesia. In reconstructive surgery the tissue is *in need of maximum* vitality. As local anesthesia reduces this, it is better to use block anesthesia. It is dangerous in the presence of infection except *in the line of incision. If used in a* digit it should be free from adrenalin. A catheter as a tourniquet passed once around the digit and then around the wrist and *clamped with a hemostat will keep the* anesthetic in situ. Local anesthesia, using 0.5 per cent novocain and 3 drops of adrenalin per ounce, is often useful in operating *on small areas of the* hand and forearm or in removing skin grafts. Hands are so sensitive that it is considerate to the patient to use at least for the first injection *a needle as fine as No. 30. A thrust through* thick volar or palmar skin is painful so the needle even when injecting the volar parts should be introduced through the thin skin of the sides of finger or dorsum of hand.

Ethyl Chloride Freezing. When used in conjunction with a catheter tourniquet at the base of the finger or a tourniquet *about the arm, freezing will last long* enough and cause sufficient anesthesia to drain a small area of infection or to operate on a paronychia, removing the nail. Freezing without the aid of a tourniquet is very satisfactory for removing skin for Thiersch grafts and does not harm the grafts.

An Essential in Reconstructive Surgery: Atraumatic Technic

The Two Obstacles: Infection and Trauma. Reconstructive surgery has been confronted by two great obstacles: infection and fibrosis. In order to overcome these, the following methods have been *formulated into what I have termed "atraumatic technic."* *

Through the impetus of the Industrial

* California State Jour. Med., 19:204–207, May 1921.

Accident compensation laws, and lately through the necessity for reconstruction of injuries sustained during the war, many surgeons have turned their attention to this line of endeavor

Experience teaches us that ordinary surgical procedure is not sufficient for success, and we have been brought to the realization that a new surgical technic must be developed in order to achieve results in reconstructive surgery Unlike most surgery, which consists of opening infected areas and removing diseased tissues, reconstructive surgery consists of building up parts so that motion and function will result. The difference is like that between catabolism and anabolism, and the technic which has been adequate for one has proved inadequate for the other

Returning to our obstacles, let us assume that a long and careful operation has been done. Grafts have been put in and movable parts have been rebuilt so that they are mechanically right for function All too probable is it that suppuration will set in, sloughing away our seemingly good results and making fruitless our well meant efforts. Perhaps infection will be avoided, but in the wake of the surgeon is scar tissue. We will find that our whole operative area becomes congealed into a hard, fibrous, immovable cicatrix functionally useless

If we are to succeed in reconstructive surgery, we must develop superasepsis and atraumatic technic. We cannot indulge in slips of asepsis as in abdominal surgery, for there the ever kindly peritoneum stands ready to make amends for slight infection nor can we indulge in the usual amount of trauma.

Infection is caused by many other factors than slips in asepsis. The very same factors that cause fibrosis also cause infection. With the best asepsis the surgical wound is not bacteriologically clean Trauma applied to tissues will, in a percentage of cases, furnish the necessary conditions for the few unavoidable germs present to cause infection Aside from trauma, some other factors that determine infection are dead spaces, tension of the sutures, large sizes of catgut, large knots, long free ends of ligature, too many stitches, too small an amount of tissue encircled by suture, excessive amount of tissue beyond ligature, mass ligation, tension in fat, foreign bodies in fat, too close proximity of skin suture line to tissue grafts, buried foreign bodies including ligature and suture material, closure with insufficient hemostasis, excessive separation of tissue layers, drying of tissues, use of hot sponges, and the time factor in long exposure of tissues

Effect of Trauma. Assuming that asepsis has been perfected, and that the above breaks in general surgical principles have been avoided, let us now turn our attention to the factor of trauma in causing infection and fibrosis

Gross Trauma The trauma commonly seen in surgical operations is as follows Tissue is torn, pinched, crushed, twisted, pulled, rubbed, scraped, and picked to shreds, with a gross disregard for not only its microscopic structure, but even for its macroscopic structure, and also with a disregard for the amount of physiologic tissue reaction that will result from the trauma. It is common to see an operative wound so traumatized that at the time of closure the tissue is ragged, shreddy, and hemorrhagic. It is red and oozing, the anatomic parts are no longer differentiated, and the tissue has lost its consistency and is flabby and shapeless How different in appearance such a wound is from one which has been atraumatically handled. Here we find a clean, dry wound, with pale, smooth, glistening tissues still in their natural colors and with their anatomy clearly differentiated. Its histologic structure has not been damaged and in the healing there will be but little tissue reaction.

Histologic Conception of Tissues If our conception of the tissues be a histologic one, we will appreciate them as being made

up of a mass of succulent cells, held to each other by a delicate meshwork of white fibrous and elastic tissue, nerve fibrils, and lymphatic and blood capillaries. Let us pull or crush this tissue to the degree of tissue strain. What happens? The cells are ruptured and their protoplasm escapes, the fibers of connective tissue and the nerve fibrils are fragmented, and the blood and lymph capillaries are ruptured. Protoplasm, lymph, and blood escape into and balloon out the interstices of the tissues, and the histologic structure of the tissue has been reduced to a pulp Animal cells have the characteristic of irritability and react greatly to such trauma. This physiologic reaction leads to cicatrization throughout the damaged block of tissue, and its normal consistence will never be regained

With this microscopic conception of the tissues let us think of what can be seen *daily in almost every operating room,* and acknowledge to ourselves that there is far too much trauma. The eye specialist handles the eye carefully, and the brain specialist handles the brain carefully, but the general surgeon often works away in apparent oblivion of the fact that he is inflicting irremedial injury to the delicate live tissues in his grasp One often forgets to gauge carefully the degree of force used in retracting or pulling tissues, and pulls even to the degree of macroscopic laceration Gauze is harsh on tissues, and when we rub with it unlimited times in an effort to wipe up the blood, are we not unmindful that each time the tissue is sponged, trauma is inflicted? With blunt dissection, tissue is *microscopically torn in a wide zone* and is often picked and shredded to raggedness, even to the naked eye. Dull needles necessitate the use of an undue degree of pinching with forceps in order to hold the tissue for sewing Dull knives and dull scissors do more damage than sharp ones, and call for more strokes Hemostats are often used to grasp living tissues, and even skin. When we use hot sponges to stop hemorrhage, we are unmindful of the fact that tissues react to an excessive amount of heat. By poor teamwork, puttering, and unskillful handling, the time of an operation *may be so prolonged that the tissues* are dried and suffer a long duration of trauma and exposure Tremor makes trauma, and the trauma makes fibrosis Tremor on the part of the assistant or operator prevents accuracy and leads to a nervously moving field, loss of composure, and repeated inaccurate strokes of the instrument. Last, but not least, much trauma is caused by repeated motions when one motion should accomplish the purpose. Fussy, aimless, and ineffectual manipulations of the tissues result in countlessly repeated motions, and every impact means a traumatism It is common to catch oneself groping for an idea by manipulating the tissues on letting the fingers precede the thought instead of *the thought preplanning the movements* of the fingers.

Prevention of Trauma. DELICACY, PLANNING, AND TEAMWORK. Let us now consider ways and means of preventing trauma, so that infection may be lessened, so that fibrosis may be reduced to a minimum, so that wounds will heal with the least amount of tissue reaction, and so that we will succeed in reconstructive surgery All tissues—even of such low dignity as skin, tendon, or muscle—should be handled with as great an amount of gentleness and *delicacy as practicable* even as one would handle a brain Let the degree of force used be cultured and always below the degree that would cause microscopic tissue *strain for* that particular tissue. This necessitates a nice conception of the histologic strength of the tissues. We should maintain a veneration for the tissues and keep our mind always on their postoperative reaction.

In order to avoid the trauma of sponging a blood-pressure band should be used as a tourniquet in operations on the extremities so as to have a bloodless field. It may

be removed before closing and then after pausing long enough for clotting to occur in the small vessels, the remaining bleeders should be tied with double, triple, or five 0 catgut. Scissors, knives, and needles should not be boiled, as boiling dulls their edge Tissue forceps should hold more by retracting than by pinching Unless for special purpose, only pointed hemostats should be used, so that the vessel itself will be caught, and not the surrounding tissue Except for catching vessels hemostats should not be used to grasp tissue that is expected to live

It is important to arrange the light to the best advantage, to make an adequate incision so the work will not be hampered, and to make the complete length of the incision at the beginning of the operation, so as to have the maximum benefit of exposure. Time used in arranging parts for ease of work is well spent The part operated on should be held in a plane perpendicular to the operative line of vision Parts should be delivered, if possible, for greater ease of work.

The duration of an operation should be reduced to a minimum. This can be done by developing teamwork, as the many tiny pauses caused by an assistant who is just slightly behind schedule due to his slow reflexes and lack of anticipation count up very appreciably Hemorrhage causes much delay, but this can be more quickly controlled by remembering that exposure is the secret of catching a bleeding vessel Knowledge of anatomy, use of simple methods, avoidance of depending on assistants, and development of skill will help to shorten the operative time.

Control of Movements One of the most important factors in atraumatic technic is conservation of movements Let each movement be studied, preplanned, purposeful, accomplishing its purpose in the single action, and not be repeated There will then be the one impact or traumatism instead of many All movements should be direct and to the point. In order to reduce the operative time, the excursion of the surgeon's hand from one place to another should be rapid, but at the end of the motion when the tissue is acted upon the motion should be slower and under control The motion should be cultured and with the maximum degree of gentleness that will accomplish the act Thought should always precede the motion, and even go far enough ahead to anticipate the next motion

False motions are of no avail and only complicate a procedure and upset composure. Contrast the old time pianist, who swayed his head and body and let his hands fly high in the air, with one of modern teaching who sits balanced erect and stationary, and concentrates his whole attention on his only moving parts—his fingers. Watch a skillful mechanic at his work. He wastes no motions, and each one accomplishes what it attempts How far behind the mechanics we surgeons are in this aspect of our work. In factories efficiency experts, in order to demonstrate the value of trained movements, have attached electric lights to the hands of an unskilled workman while he did his particular job, such as folding handkerchiefs A moving picture was then taken and a manikin of wire was constructed, showing the actual excursion of the lights. After training the man to do the same job with the fewest and most direct motions, a similar manikin was made for comparison. Its simplicity and shortness of wire compared with the first manikin was, of course, a contrast and the man could then turn out much more work in the same length of time and with greater ease.

In order for us to master conservation of movements in operating, we should practice it in everything we do in daily life, such as dressing and undressing, or working with our car Why should we cultivate conservation of movement? It diminishes trauma, it reduces operative time, and this lessens the duration of tissue abuse. It allows one to complete more difficult and

extensive operations than would otherwise be possible It develops skill This habit formed allows the mind to reflect on the more important aspects of the operation. It makes for composure, it allows slower and more accurate movements.

If each movement accomplishes something, and if movements follow each other in rapid succession, our operation will be finished in a very short time

THE STATIONARY FIELD Another very important factor in atraumatic technic is maintenance of a stationary field. This means the control of tremor on the part of both operator and assistant. Some assistants are very nervous and impart a nervous tremor, choreiform in nature, to the field. When they move one hand they must move the other, or even their head and feet. They fairly gesticulate with the operative field This uncertain jogging or vibrating of the field makes it impossible to do accurate work. One never knows where the knife edge, hemostat, or needle will meet the tissue. If the amplitude of the vibration be three millimeters, how impossible it is to be accurate within one millimeter The miss of the instrument is equal to the amplitude of the jog The surgeon is trying to do the impossible Uncertainty is brought in. His composure is upset, and soon all in the room become irritated

Usually, the operator is not aware that it is the moving field that is causing the trouble. When two objects are moving, accurate connections cannot be made. Let a person attempt free handedly to pass thread through the eye of a needle that another person holds also free-handedly Their combined tremors make it impossible. In operating, if one person is moving, the other should remain motionless To test one's tremor, hold free-armed before one a pin in each hand, so that the points remain one millimeter apart, and the two pins form a straight line. To record a tremor, let someone with a braced ruler slowly rule a line across a piece of cardboard held free-handedly by the person to be tested. The deviation of the line from the straight will give a record of the tremor Tremor and a moving field account for many an inaccurate and repeated motion in surgery, thus adding materially to trauma. Tremor may be controlled by bracing, relaxation, and poise.

BRACING AND LEVERAGE. In order to see how the jeweler does his fine work the author went through one of their manufacturing houses, and what he saw can be applied to surgery The jeweler sits balanced on a stool. He wraps his legs about the stool. With this foundation he braces his elbows against his body or his bench, and rests his forearms on two rollers which project five inches from the edge of the bench. Out jutting from the edge of the bench is a piece of wood on which his hands are braced. The piece of jewelry is steadied in a notch in the wood He eliminates tremor by this elaborate system of bracing He magnifies his accuracy through lever action. Using his braced fingers as a fulcrum, the point of his instrument can be very accurately controlled by concentrating on the movement of the end of the long lever arm, his elbow or shoulder Similarly the artist uses his mall stick. With these principles, the surgeon using such instruments as scissors or hemostat may brace, with an extended finger, with his forearm, with his other hand, etc.

METHODS FOR ACCURACY The basic factor in the art of movements of skill is relaxation The whole body is placed in relaxation, and the only part that moves is that part required to execute the movement. In addition to relaxation the whole body is also put in poise. This is balance. Motion with the hands loses its refinement if the back is off balance, with consequent strain on the back muscles subconsciously diverting our attention or effort. With the body in relaxation and poise, our attention to it is relieved, and 100 per cent of our concentration or effort can be concerted on the

movement of the hand If now we brace down on some of the fingers our whole amount of effort and attention is concentrated to just that part which is distal to the last brace. In this way we can use the maximum amount of refinement in the motion, and the tremor can be avoided

Importance of Atraumatic Technic. If a Wolfe graft is not handled atraumatically, that part of it which has been abused turns black with necrosis toward the end of the first week If the delicate membrane about a tendon (epitenon) becomes scratched, an adhesion between the tendon and its sheath forms at this point, preventing function If nerve suture is not done atraumatically, fibrous tissue will form between the two ends and around the junction tightly encircling it and preventing regeneration. If trauma accompanies the placing of grafts, serum forms about the grafts This becomes infected and the grafts slough out. If infection does not occur, the tissue reaction replaces much of the graft with scar tissue and binds it tightly Many more disasters due to trauma can be cited, but suffice it to state once more that unless we use atraumatic technic the higher surgery of reconstruction cannot be accomplished. If mastered, it will greatly facilitate the simpler forms of surgery and give not only an easier convalescence, but very little local reaction The reduction in the amount of local reaction is surprising

Atraumatic technic not only does much of what is claimed in anoci-association, but has the advantage of insuring an approximately reactionless healing and of reducing infection. We refer to the art of surgery, so why not make it an art and, like the artist, be engrossed in its handicraft?

SPLINTING WITH PLASTER OF PARIS

Nonpadded Plaster Bivalve No splint will *hold as* one molded to the limb, such as nonpadded plaster of Paris The old

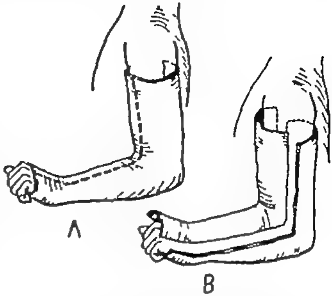


FIG. 67 (A) Incorrect way to cut an overly tight cast. A midline anterior and posterior cut is made, but this does not relieve the pressure in the antecubital space which may lead to Volkmann's *ischemic contracture.*

(B) Correct way to loosen a cast with two longitudinal lateral cuts. The front member is lifted forward from the antecubital space.

padded plaster cast did not immobilize and caused more pressure sores The padding became displaced so the pressure of the cast was upon the few bony prominences instead of being evenly distributed. Applying the plaster circularly and with some tension is to be condemned because of the danger of pressure sores, ischemia, or gangrene Plaster, instead, should be laid on the limb in flat slabs When a little over half the circumference of the limb is covered, an *encircling gauze* bandage is used to mold it in place. When this first layer of plaster is fairly hard, the gauze is cut its full length longitudinally to the limb to avoid constriction A layer of wax paper or cellophane is then laid over the limb and the back half of the cast is applied as a flat slab over it. Another gauze bandage is then wound over all This bivalve is for safety, so in case the limb swells the lid can be lifted and, after spreading, the cast replaced. In applying the nonpadded cast, the plaster is *laid directly on the skin, but is placed* without any tension. It should be molded

accurately to the curvature of the limb and around bony prominences guarding from pressure the head of the ulna and the internal epicondyle. When encasing a hand it is found convenient, due to the many curves, to use multiple small, folded strips of plaster instead of a large slab These fit the contours better and reinforce the cast wherever needed. One thicker strip is used to complete the cast by passing across the cleft of the thumb and the palm between the thenar and distal palmar creases. This is made strong enough to stand the wear of work and narrow enough to allow free motion of the thumb and proximal finger joints While the cast is being applied the joints should not move or pressure-provoking ridges will form.

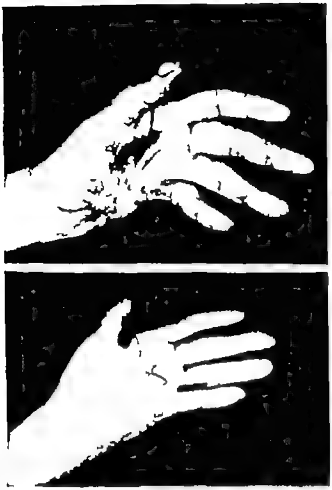
Position of Joints Freedom for Movement. Joints should never be put up in a cast at their limit of flexion, because they will be damaged from pressure on the articular cartilages and tension on their ligaments. Instead, joints should be eased off a little from complete flexion Unless there is reason to do otherwise in making a cast, the joints should be placed in positions of function and the thumb and fingers should be free to move. The wrist should be moderately dorsi and ulnar flexed and slightly supinated, and the elbow should be at a right angle. In the palm, the cast should end with a thick edge for wear—not a feather edge—and should stop at the distal palmar crease so the proximal joints of the fingers are free to flex. The dorsum of the cast ends at the knuckles. The thumb should be in a forward position from the hand and its proximal joint should be entirely free to move. If it is desired to stop the motion of pronation and supination the cast should be continued to the axilla. This can be done by a sugar tong U ribbon of plaster taking in the upper arm and elbow and held in place by a gauze bandage.

A cast on the hand should either run well up the forearm for good leverage in immobilizing the wrist or stop at the base of the hand so the wrist will be free in all its motions. After drying, a coating of shellac or Duco is of advantage if a cast is to be worn for a long time.

Common mistakes in applying casts are to place the wrist straight instead of dorsi flexed, to prolong the cast beyond the distal palmar crease so the fingers cannot be exercised, to disregard the transverse palmar arch and make it flat, to have the thumb at the side, and to leave the cast on too long

Danger of Tight Casts. Volkmann's ischemia is caused by pressure on the veins in the antecubital space, so all elbow casts should have complete freedom in the crease of the elbow It is well first to lay a small fluff of sheet wadding along the crease and so to apply the plaster that this region will be free from pressure. Movement of the elbow while the plaster is setting works a plaster ridge into this crease. In relieving pressure which develops in a right-angle elbow cast, it is an error to slit the cast in its anterior and posterior longitudinal lines because this will not relieve the pressure in front of the elbow Instead, two midlateral cuts should be made the full length of the cast, one along the inner and the other along the outer side, and the front half should be lifted from the rear half through its full length. It is impossible to relieve the pressure in an elbow cast by making one full length longitudinal lateral cut and then attempting to spread the cast for a right-angle cast will not spread in both arms of the angle at the same time. If the cast is applied following an injury or operation, the arm should be elevated for the first one or two days. Frequent inspections are imperative, as there is always danger of pressure points, ischemia, or gangrene. If the beginner is not taught this he will learn it after bitter experience and will ever after be on the alert to ease constriction or pressure by slitting bandages and spreading casts. The digits should be exposed to view when a cast is applied to ascertain the condition of the circulation. Pain and cold, cyanotic, anesthetic swollen tips of an extremity are the danger signs. A finger

A



B

Fig. 68 Case P B Seven months previously his hand was caught and held by a hot metal roller resulting in a deep contracting palmar scar adherent to the tendons and preventing extension of the fingers as shown in (A)

Operation The scar tissue was excised and the denuded area so left was covered with skin from a tubular pedicle from the chest, as shown in (B) (Courtesy Surg Gynec., and Obstet. 39 106 No 6 1922)

A

B

Fig 69 (A) Cicatrix on forearm replaced by tubular pedicle skin.

(B) Skin in place. Ready for placing new extensor tendons.

which has been operated upon must never be enclosed in a complete encircling non padded cast, as it is sure to swell and need relief It should be bivalved, as described above An intervening sheet of wax paper or cellophane is preferable to petrolatum for later ease of separating the halves of the bivalve.

Splinting to Protect Tendons and Skin Plastics. There are several special uses of plaster of Paris in splinting the hand After repair of flexor tendons, a flat slab of eight layers is laid on the dorsum of the hand and forearm to hold the wrist in flexion Following repair of extensor tendons, a similar slab is laid on the volar aspect to hold the fingers and wrist in doral flexion. After a plastic operation on a youngster for syndactylism, burn contrac tures, etc., in which full thickness grafts or *vulnerable skin flaps are used, the hand and* fingers should first be fastened on a skeleton metal splint. Outside this, there should be a casing of plaster of Paris enveloping two-thirds of the circumference of the hand and the circumference of the arm. This is completed by adding a removable lid to the hand as a bivalve. For ease of inspec tion of the finger tips, a glass microscope slide can be placed in the cast as a window In children, to prevent slipping the plaster cast should extend to the axilla with the elbow at a right angle.

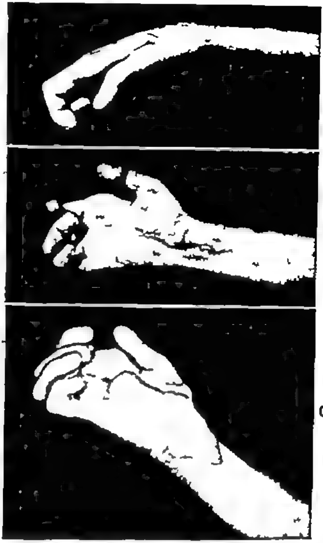
A

B C

Fig. 70 Case B E (A) Following an infection starting on the dorsum of the ring finger there was much cicatricial de formity and adhesions of tendons on the dorsum of hand and forearm.

(B) The scars were excised covering the denudation by sliding and using pedicled skin.

(C) There was improvement in appear ance, nutrition, and motion.



A B C

Fig 71 Case W C

(A and B) Seven months previously a wire carrying 2 400 volts contacted the palm and another the shoulder for ten seconds. Severe infection with sloughing of flexor tendons and median and ulnar nerves, rendering the hand useless.

(C) The cicatrix has been excised and replaced by good pedicled skin, greatly improving the nutrition. Later the tendons and nerves were repaired.

Other Uses. When traction is applied to the digits by extension splints or by the Böhler wire method, there is nothing better than nonpadded plaster of Paris about the hand and forearm as a foundation to give attachment and stability to the extension. This may be on either the volar or dorsal aspect only and embedded in it is the wire outrigger from which the fingers are pulled into flexion or extension To draw the distal two finger joints into extension, a layer of felt is first placed under the plaster across the backs of the row of proximal finger seg ments to act as a fulcrum. Similarly, after a recent wound is excised and its tissues repaired, an encircling cage of Cramer wire embedded in the front and back of the plaster affords air dressing, and when enclosed by gauze gives adequate protection from outside injury

For holding a finger for rupture of the insertion of the extensor tendon, with distal joint in extension and middle in flexion,

plaster is better than any splint. A dry plaster scroll is placed over the finger After dipping finger and plaster in water the position is maintained by pressing the thumb against the finger until the cast is hard (Smillie) Plaster casts wedged or reapplied at intervals are especially efficient in gradually forcing joints to new positions The pressure is positive, not elastic, and the patient will not remove or loosen them as he would splints Elastic splinting, however, is preferable After arthroplasties of the proximal finger joints a dorsal plaster splint will maintain flexion

Occasionally, there is edematous swelling in a hand that should be worked out. For this, a casing of Unna's paste is excellent, followed later by an Ace bandage.

SPLINTS

Purpose

Our object in splinting is to immobilize, to maintain the limb in a certain position, or *gradually to draw joints into more* flexion or extension. We immobilize in treating infection, for holding fractured bones, and for better healing after trauma or surgery We maintain a limb in a certain position to protect newly repaired tissue, such as tendons or nerves, from breaking, to keep paralyzed muscles in relaxation and in other cases to allow the tissues to grow until they adapt themselves to the desired position We gradually draw joints into more flexion or extension in order to correct deformities, to place the limb in position of function or to give more motion to a joint.

Splints to immobilize should be form fitting and in broad contact with the limb They should encircle the limb, especially at the joint and at the two ends of the longest possible lever arms.

Splints to draw a joint into flexion or extension should have three padded areas for broad pressure one at the level of the joint as the fulcrum, and the other two on the opposite side of the limb but as far from the fulcrum as possible to give maximum length of leverage

Requirements

Splints should be standardized as much as possible to facilitate the large volume of work by many people. They should be cheap and light but still not offensive to the eye, easy to make, and of simple construction, instead of elaborate and with too much machinery Splints should be easily adjustable and not too bulky Bulky splints are in the way and so are prominent outriggers It is more convenient for the patient if the splint can pass through a coat sleeve.

Materials

Various materials are used Yucca wood which can be shaped when immersed in hot water, wood such as tongue blades, malleable wire screen, steel strips riveted to galvanized iron sheets, sheets of aluminum or Duralumin, thin molded slabs of plaster of Paris, Castex, celluloid, or various plastics.

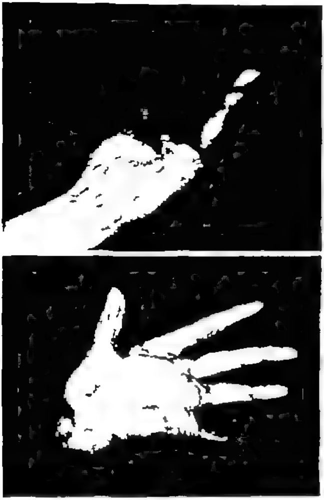
Flat steel rods bend better than do those of Duralumin Aluminum in sheets is quite pliable and workable Duralumin is firmer but like galvanized iron is difficult to shape in two curves

At operation, plaster of Paris is usually used, though metal splints are useful as they are adjustable and can be boiled.

Castex is light and when used in many narrow strips can be molded about the curves of a finger, but it tends to shrink and distort.

Celluloid is useful It can be given a curve in one direction by heat, and can be fastened to itself with acetone. To fit two curves it should be applied in strips and cemented together with acetone. If made into a cylinder to fit over a finger, it should contain multiple punctures made by a red hot wire to prevent sweat from accumulating on the skin. Celluloid dissolved in acetone can be painted on the plaster form of the finger or limb as a syrup, adding several

A



B

FIG. 72 Case E. W., aged 27 When two years old she fell with her hand in a fire.

(A) Flexion contracture from burn, stunting the growth of the hand.

(B) Cicatrix replaced by tubular pedicle graft. Little finger is short.

coats after each layer of fabric, to make a form fitting splint. It is smoothed with sandpaper and more syrup

Plastic Splints

There are now available synthetic thermoplastic materials that are malleable under heat and pressure. Examples are acetobutyrate cellulose acetate, and vinyl chloride known as vinylite. The first two burn slowly but the third scarcely burns. They are all clear, transparent, or colored and are readily curved in one direction under heat and also enough in a second direction to be practical Under pressure in a die they flow to any form. They bend somewhat in water at 220°, but better in oil up to 350° F

Vinylite is inexpensive, transparent and obtainable in sheets of any thickness It readily softens in the heat above the flame of a Bunsen burner and then cuts easily with scissors A strip is dangled by forceps in the heat and then quickly molded over the patient s finger, hand or forearm. A single layer of cloth is enough to protect from heat and the operator can use cotton gloves to draw the splint around and along the limb Any shape or size of splint desired for the hand may be promptly produced.

A supply of splints both volar and dorsal may be quickly made over metal finger forms, fashioned in various curves and sizes and held in a vise One can also lay the vinylite on a coiled spring the size of a finger and then bend it to any curve. Vinylite hardens at once can be trimmed on a bench grinder, drilled and glued with acetone

Celastic (colloid treated fabric) in sheet form when dipped in ethyl acetate is pliable so it can be molded on a form. If allowed to evaporate over night, it becomes rigid. It may be obtained from the United Shoe Machinery Corp, 104 Federal Street, Boston, Mass

Sizes of Materials

Spring cock up splint, spring wire 102 inch
  Blue steel spring .045 x 5/8 inch
Knuckle bender wire rods 082 inch
Thomas suspension splint, spring wire, 075 inch
  For thumb 056 inch
Oppenheimer splint, .075–.067 inch
  For thumb .033 inch
Cold-rolled steel, 3/8 x 9/64 inch
Finger extension splint, blue spring steel,
  .032 x 19/64 inch and 021 x 29/64 inch
Safety pin splint, spring wire .033 inch
Rubber bands, Eberhard Faber No. 31

TYPES

Flat volar splints or straight cross bars in the palm should be avoided because they disregard the natural transverse concavity

in the palm and cause manus plana or flat hand with loss of opposition of the thumb Unless for some special reason, splints should hold the wrist in the position of function of 30° dorsiflexion, the thumb in the forward position for grasp, and should leave the metacarpophalangeal joints of all of the digits free for movement, the principle being to maintain positions of function and limber joints. The banjo type of splint should be condemned, the straight pull on the fingers in extension leaves them stiff and also results in malunion of fractures When it pulls the tendons straight instead of in the position of function, the bones are thrown out of alignment When used to flex the fingers, the line of pull of the banjo is wrong, it places lateral strain on the fingers, whereas on flexion the digits should converge toward a central point, the tubercle of the scaphoid

Prolonged use of splints stiffens the

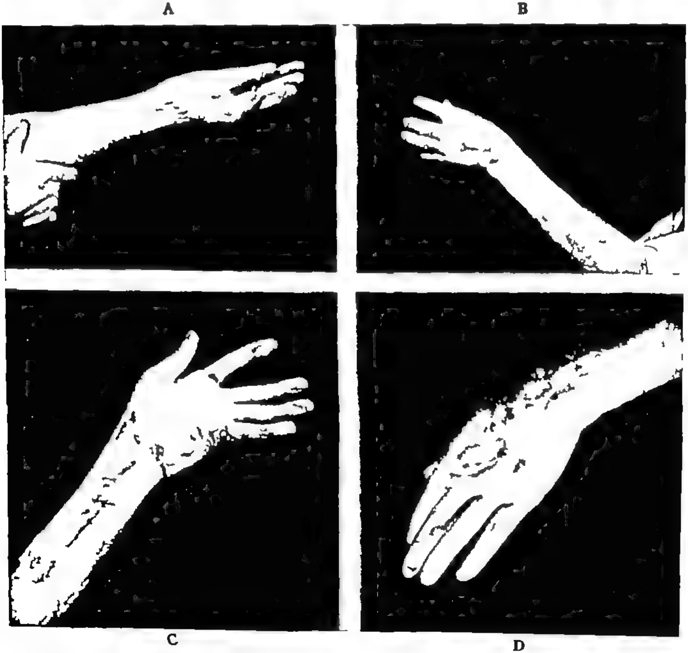
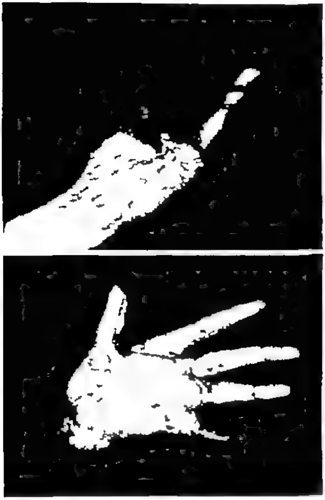


Fig 73 Case H. G M.

(A and B) Hand was encircled and tightly bound by cicatrix. The skin had been ripped from it in an elevator

(C and D) Cicatrix was excised and replaced by good skin by a tubular pedicle from the abdomen, restoring nutrition and freedom of movement. Photographs taken two years later

A



B

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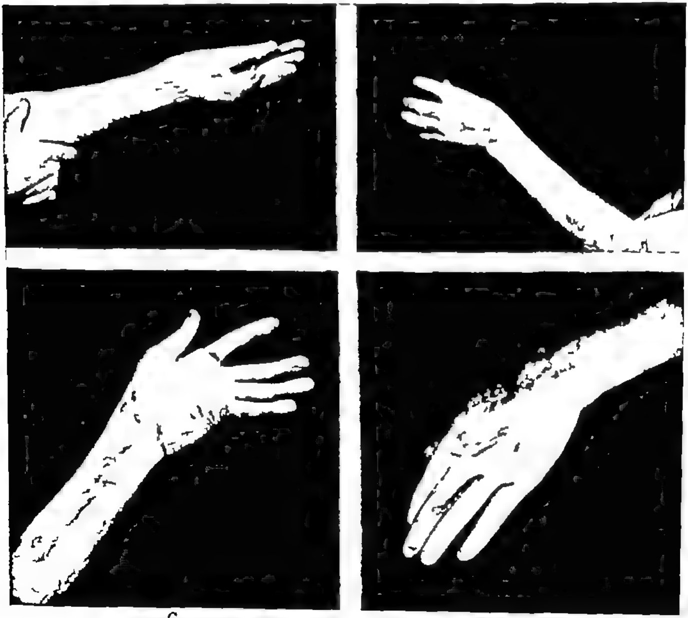
Prolonged use of splints stiffens the

A B



C D

Fig 73 Case H. G M.

(A and B) Hand was encircled and tightly bound by cicatrix. The skin had been ripped from it in an elevator.

(C and D) Cicatrix was excised and replaced by good skin by a tubular pedicle from the abdomen restoring nutrition and freedom of movement. Photographs taken two years later

hand. This is particularly so when it is held by encircling straps which by constriction create edema, thus completing the two causes of stiffening—swelling and immobility For traction splints for fractures see Fractures, in Chapter 13

Active Splinting of the Hand by Spring or Elastic

Splints that are used to immobilize inflamed or healing parts, such as osteomyelitis, fractures or after plastic work to protect repaired tendons and nerves, must of necessity be stationary In the following a system is outlined of using elastic or spring splinting to coax joints around from the position of nonfunction into that of function and to maintain them so Spring splints are, also, advised as a substitute for paralyzed muscles in peripheral nerve injuries The springiness may be furnished by rubber bands, piano spring wire (single or double in a loop), or by flat blued ribbon spring steel The wire and flat steel may be obtained in all sizes. Holes can be made through the spring steel by punching with a nail set on a lead block or by a drill, if it is sharp and its edges are ground round instead of straight. A punch is best.

For forcing joints into other positions spring and elastic splinting was found to be more efficient than was unyielding splinting Rigid splinting makes rigid hands. In spring or elastic splinting the joints are never strained to excess nor are they immobilized. Active splinting is physiological splinting Hands need mobility to thrive. If kept still, they atrophy and stiffen The hands work continuously against the springs or elastics and with these splints are actually exercised. In this system we splint to mobilize, not to immobilize. It is functional splinting. Muscles pump away their stagnant fluids washing out the toxins tendons keep gliding and joints moving thus adhesions are prevented and these structures kept normal.

In active splinting the splint should be light and not in the way of occupational therapy or other work. It forces the joints around into the position of function, that is, the wrist into dorsiflexion, the proximal finger joints into flexion, the proximal arch into a curve and the thumb into the position of opposition. Also, it extends clawed fingers In the position of nonfunction, if there is a little movement, a hand is useless but in that of function, it is useful for pinching and picking up objects When a hand can do thus, it will be used more and more continually improving with work.

The illustrations of elastic or spring splints are grouped together at the end of this chapter Sets of these elastic or spring hand splints can be obtained from H Weniger, 143 Valencia St., San Francisco

Wrist Splints

Volar The cock up wrist splint is made in many forms and of many materials. It is a basic splint in that it can be used as the foundation for attachments, such as extensions or outriggers, for additional control of the digits. It is composed of a forearm piece connected by a neck to a palm support, and is held to the hand and forearm by encircling straps or laces The forearm piece ranges from one longitudinal strip of metal with two curved cross bars to a complete encirclement of the forearm. Usually, it consists of a curved metal sheet over the lower two-thirds of the volar aspect of the forearm. Straps and buckles encircling the forearm at each end hold it in place. The palm piece is oblique and is either a spindle-shaped rod or a rod curved to fit the arch of the palm curved up at the sides or not, or it may be ovoid in shape. There may or may not be a strap from it encircling the hand The palm piece should rivet to the neck so its obliquity can be changed to fit either hand. The neck may be either an integral part of the splint as a whole, or preferably a flat rod that can be bent to the desired curve. When a wrist is being forced into dorsiflexion by a cock up splint, it will be found that the splint slips distalward and ceases

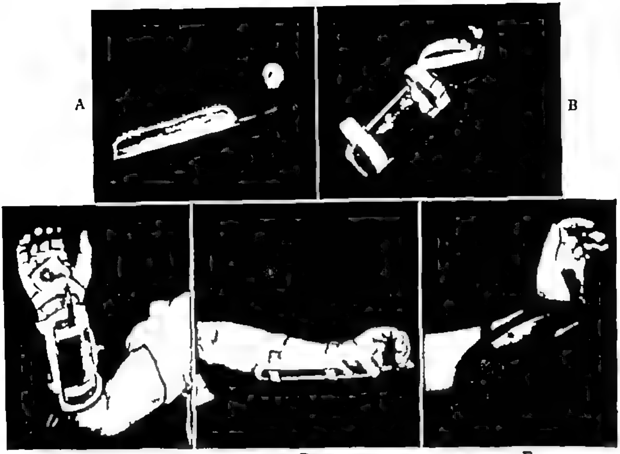


FIG. 74 Wrist splint, volar or cock up splint of aluminum sheet steel rod and ovoid palm piece. One strap to the wrist must be oblique to keep the splint from displacing down the hand as it forces the wrist in dorsiflexion.

(A and B) Splint easily made in an office. Straps are interchangeable through slits punched in the aluminum.

(C) Volar view

(D) Well padded with felt.

(E) Will give strong dorsiflexion if desired

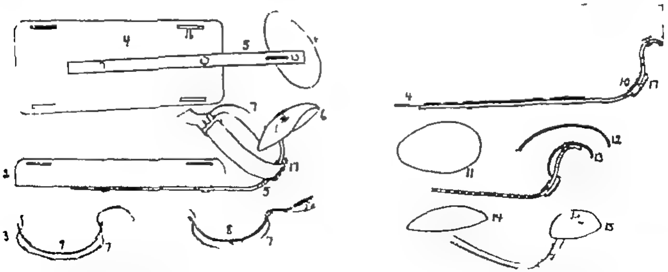


FIG. 75 Cock up splint. (1) Bottom view (2) Side view (3) End view (4) Forearm piece slightly curled out at lower end. (5) Neck piece. (6) Hand piece. (7) Web strap (8) Forearm piece, distal end view (9) Forearm piece proximal end view (10) Neck piece side view (11) Hand piece before curved. (12) Longitudinal curve of hand piece. (13) Transverse curve of hand piece. (14) Side view hand piece. (15) End view hand piece. (16) Slots for web straps. (17) Wire loop to hold strap encircling wrist.

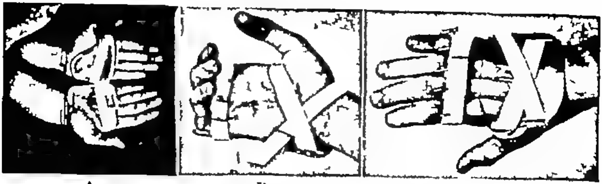


FIG 79 Palmar splints to hold the palm extended and immobile, as after an operation for Dupuytren's contracture to ensure healing

(A) Volar type Fits the palm, arched and open for ventilation.

(B and C) Dorsal type which gives more immobility The distal strap loops alternately over the back of each rod and the volar aspect of each proximal finger segment, immobilizing the distal crease in the palm. Should be applied after operation for Dupuytren's contracture.

arm piece with 4½ in. of overlapping. The distal end is curved to fit into the hand piece to which it is riveted. The neck part is curved with the curve exactly in accordance with the shape of wrist and hand. At the maximum convexity of this curve a passageway to hold a web strap in place should be made. This passageway should not prevent the neck piece from being bent as desired or cause it to break at a large rivet hole. A good method is to drill two holes just large enough for a wire to be placed through them, so it can be soldered to itself into a flat loop

HAND PIECE. This is hammered or pressed from an oval shaped piece of duralumin 2⅞ x 1¾ x ³⁄₆₄ inches in size, so that it forms a sharp curve transversely and a milder one longitudinally to its axis. It is curved to fit comfortably into the palm of the semiflexed hand. There are no edges or sharp corners pressing the palm and the shape fits the longitudinal and transverse arches of the semiflexed hand The finished curved piece measures 2½ x 1⅜ inches the depth of the curvature being ½ inch The hand piece is riveted at its center to the end of the neck piece. Placed in a diagonal line it fits one hand and when turned to the other diagonal it fits the other hand, the narrower part of the oval being on the thumb side. A hand piece can also be fashioned of wood on a bench grinder

The splint works distally especially when used to dorsiflex the wrist, unless a web strap is placed through the wire compartment in the neck piece and made to run diagonally upwards and backwards to loop about the dorsum of the wrist. This will keep the splint from slipping distalward. The two circular straps through the slots and about the forearm hold the splint in place. The distal circular strap as an alternative may be prolonged and used as a figure-of-eight crossing the back of the carpus and looping through the compartment in the neck piece.

This splint is a basic splint. To it may be riveted extensions to hold the thumb or finger in extension or to act on the digits in other ways.

Spring Cock up Splint. A spring cock up splint differs only in the neck piece which may be either of two piano spring wires (.105 inch) or of ribbon spring steel (.047 x ⅝ inch) For greater spring they are fastened rather proximally on the forearm piece The spring wire is looped on itself and bent into the proper curve To the sharp U loop is brazed a flat piece to which the hand piece is riveted. The compartment for the oblique strap about the wrist is made from a prolongation from the forearm piece. The wires are riveted to the forearm piece by two strips of metal curved about each wire. Flat spring steel is preferable. After having been given the proper goose neck bend, it is fastened by riveting This spring splint is excellent for bending the wrist into dorsiflexion

EXTENSIONS TO COCK UP SPLINT These may be riveted to the neck or forearm piece

They are to hold the thumb or fingers in extension after the repair of extensor tendons, and consist of a rod with a metal gutter at the end or flat piece for several fingers Also, the palm piece can be prolonged distally to support the proximal finger joints

To Flex the Proximal Joints To the belly of the cock up splint is riveted or fastened by screw clamp a flat rod on the end of which is mounted a triangle of stiff wire so as to present out in front of the fingers, as the outrigger, a transverse wire Over this is threaded a piece of metal tubing to act as a roller Over the proximal segment of each finger is a soft leather loop to which is attached a rubber band The bands pass over the roller to a hook in the belly of the splint. As the proximal finger joints bend the wire outrigger is bent backwards to pull proximalwards, always at a right angle to the finger segment.

Dorsal. Three separate pieces of aluminum or other sheet metal are molded to the dorsum of the hand, wrist, and forearm respectively, and riveted to a malleable metal strip Slits punched through the edges of the sheet metal hold the removable web belts with buckles in place. The metal strip can then be bent so that this flat splint will hold the wrist in any desired position from palmar to dorsiflexion. In the latter case, the flat splint may be prolonged to the finger tips by an additional metal cross-sheet and strap to keep the fingers in extension.

Flat wrist splints are especially useful after repair of the flexor and extensor tendons to keep them relaxed during the month of healing They are useful after nerve suture to allow the flexed wrist to extend gradually

For the purpose of gradually forcing a wrist into dorsiflexion, the spring cock up splint with the oblique wrist band is used, and to force it gradually into palmar flexion the padded dorsal wrist splint will suffice.

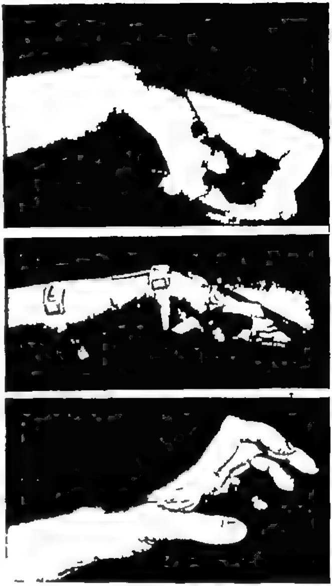


Fig. 80 Reversed cock up splint with extension to draw fingers into extension. Case J D., aged 48

(*Top*) Following encephalitis the hand was drawn by the unequal pull of the muscles into contracture of three years standing. By the principle of slow mild, steady traction the joints were gradually straightened and the flexor muscles stretched.

(*Center*) Commencement of treatment.

(*Bottom*) Result obtained in 10 months by this and later other splints.

Strength returned to the overstretched extensors and good function continued. (Courtesy Surg Gynec., and Obstet., 9 260 1924)

Note Should have had felt-padded extension to prevent hyperextension of proximal finger joints.

For Pronation and Supination

For this it is necessary to encase the arm in a right angle elbow splint as a basis. The wrist is grasped firmly enough with a

broad oval ring or the hand and wrist are encased in plaster To produce supination correctively two extension rods from the forearm piece of the elbow splint are used as attachments to draw, by a rubber band from each rod, the hand or wrist member in rotation Exercise by twirling a dumb-bell or stick increases this motion

Hand Splints

A large rubber sponge is useful postoperatively, bound to the palm of the hand with a bandage. It furnishes pressure over the dressings and immobilizes the hand and fingers.

Hand-spreading Splint. This is useful after plastic operations and especially after operations between the fingers as in syndactylism It consists of a sheet of metal molded to the dorsum of the hand and held there by two encircling straps, one of which is about the wrist. Soldered to this sheet are five diverging malleable metal rods, each to extend down the back of a finger or thumb and by a shallow gutter piece at its end to support the digit. At the end of the operation, after padding, each finger is fastened to its respective gutter by a piece of sterile adhesive tape, and in this way the fingers and thumb are held spread and extended. It makes them quite accessible for dressings in the interdigital clefts (Fig. 84)

Palm Splints. Incisions in the distal crease of the palm are slow in healing because of motion. This applies especially after operations for Dupuytren's contracture. The distal crease in the palm can be

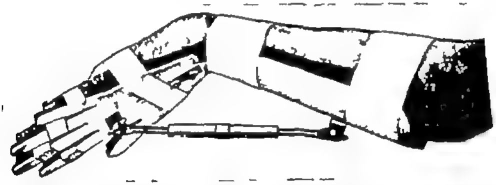
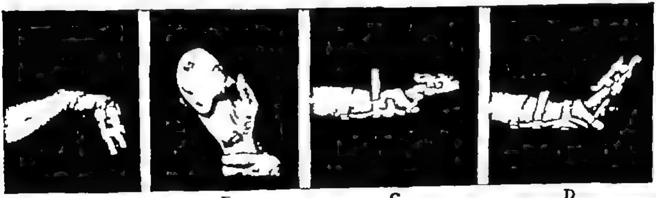


FIG. 81 Volkmann s ischemic contracture splint (The London Splint Co) (Courtesy Bailey Hamilton Surgery of Modern Warfare Part III E & S Livingstone Edinburgh.)



A B C D

FIG. 82 Splint to extend wrist and fingers when flexor muscles are too short, as in Volkmann s ischemic contracture.

(A and B) With wrist flexed fingers are straightened between two padded metal sheets strapped together the dorsal of which has an extension arm.

(C) While a cock-up splint draws the wrist into dorsiflexion the proximal finger joints are gradually straightened by drawing the extension arm by web belt and buckle to the forearm.

(D) The extension arm is bent as necessary finally to extend both wrist and fingers.

Fig 83 Plaster splint to prevent claw hand deformity in median and ulnar nerve paralysis.

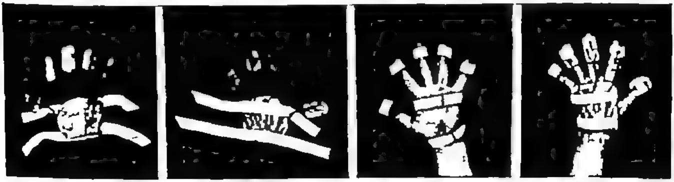
immobilized with either a volar or a dorsal splint after such operations. (Fig 79)

Volar Splint The volar splint is a sheet of metal, somewhat triangular in shape, that has been hammered to fit the contour of the palm to which it is fastened by two encircling straps. The center of this splint is laid open by making two cross-cuts and bending the four points forward away from the palm to allow ventilation and accommodate dressings

Dorsal Splint The dorsal splint for Dupuytren's contracture, which is more efficient, consists of a sheet of metal molded to fit the dorsum of the hand, to which it is strapped. Five parallel metal rods soldered to this and joined at their ends by a cross-rod extend to as far as the middle joints of the fingers. A web strap woven in turn over the volar aspect of each finger and over the back of each rod will hold the proximal finger joints in extension The palm will then be immobile and exposed for dressings, and the middle and distal finger joints will be free to move.

If one desires to splint only one or two fingers to keep the distal palmar crease from moving, a flat metal or plastic dorsal splint can be cut out to fit the back of the hand with one or more prolongations down the proximal finger segments To this, the hand and whatever fingers desired are fastened with adhesive plaster The palm will be free for dressings

To Draw Fingers and Wrist into Extension. For Clawhand For clawhand (i e, extension of proximal finger joints with flexion of distal two) an extension is made from a basic splint such as a dorsal splint strapped to the forearm, hand, and proximal finger segments By this extension the fingers are drawn by means of traction loops about each or by a rubber sponge under all of them The simplest method is to lay a plaster slab over the dorsum of the forearm, hand and proximal finger joints Over the latter a thick layer of felt should be placed under the plaster as this part will act as the fulcrum Embedded in the plaster are the two ends of a wire U The cross-piece of the U is straight and over it is slipped a piece of metal tubing to act as a roller This outrigger is placed so that it will pull the finger ends by leather cuffs and



A B C D

Fig. 84 Spreading hand splint.
For use postoperatively after plastic operations especially in the webs. Gives immobility spreading and accessibility
(A and B) Both surface wires are soldered to galvanized sheet and are bent as desired.
(C and D) Boiled for postoperative use. Padded proximal edge bent away from fold in wrist holds fingers by sterile adhesive.

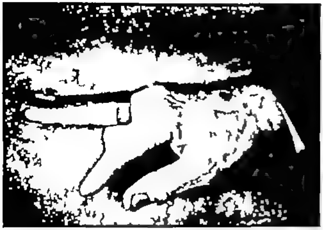
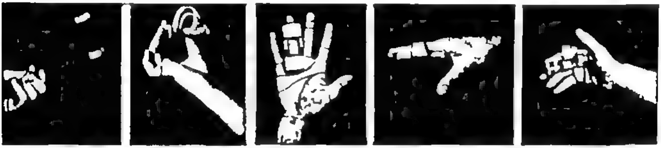


FIG. 88 Lewin's splint to extend a finger

This type may extend to the wrist have cross pieces at the wrist, hand, and fingers, and an end piece that loops over the end or laterally around the finger and can be of spring steel to gradually extend a finger

The simplest is a plaster of Paris volar slab with outrigger of a loop of wire to form a transverse bar in front of the proximal finger segments. Leather cuffs over the backs of the proximal finger segments are pulled by rubber bands over this outrigger rod and fastened proximally to a hook in the belly of the splint. As the proximal finger joints are flexed, the wire outrigger is bent so the pull will always be at a right angle to the proximal finger segments The pull is first at a right angle to the palm and finally is proximalward.

Nachlas made a splint for this purpose with an outrigger that tromboned along the forearm piece to give the correct direction of pull Luckey made one with the out



A B C D E

FIG. 89 Safety pin splint to straighten a finger

(A) Two curved galvanized iron ribbons are soldered to the ends of two rods wide enough apart easily to admit a finger between them.
(B) Padded and web belt and buckle placed.
(C and D) Splint in position. Strap draws middle finger joint between the two rods.
(E) Must be short enough to allow proximal joint to flex.
Spring wire .033 inch may advantageously replace the rods.

FIG 90 Splint for rupture of insertion of extensor tendon of distal finger joint. Hammered out of duralumin and with two malleable cross pieces over the finger the splint holds the middle joint in flexion and the distal in extension. Adhesive plaster insures against displacement.

rigger adjustable for three set positions.

A simple method is to use the standard cock up splint. To it can be attached an adjustable outrigger of wire (Fig 96D) that can be bent as desired as the proximal joints flex To avoid the friction of the rubber bands in pulling over the outrigger rod metal tubing is slipped over the rod to act as a roller The hand piece of the splint must, of course, not extend beyond the distal crease in the palm.

The metacarpophalangeal splint was used for the first bending of the proximal finger joints It consists of two flat, slightly arched, well padded sheets of metal, one pressing the dorsum of the distal part of the

proximal finger segments and the other the base of the dorsum of the hand. The sheets are riveted to a stiff metal strip which arches longitudinally over the proximal finger joints. A web strap and buckle passing through a compartment in the center of this arch draws backward the third member or padded cross-bar of the splint, which presses arched along the distal crease in the palm to draw the proximal finger joints into flexion. When the splint has drawn these proximal joints into 45° of flexion, a kid glove was worn to carry on the finger flexion still farther (Fig. 92A and B). This splint and the glove method have been superseded by the knuckle bender.

GLOVE TRACTION METHOD. For this, a web strap and buckle is riveted to the wrist of the glove, so the buckle lies on the volar aspect of the carpus over the scaphoid tubercle. A cord is fastened to the tip of each glove finger. Two of these cords are looped through the buckle and then each is tied with a bowknot to one of the other two cords. The patient can, by tightening these cords, gradually increase the flexion of the fingers. Rubber bands may be used.

KNUCKLE BENDER SPLINT. This I devised to apply the elastic principle to the metacarpophalangeal splint, to flex the proximal finger joints and carry the motion through to completion. The three points of pressure are over the backs of the distal ends of the proximal finger segments, the back of the bases of the metacarpals, and across the palm along, and curved into the distal palmar crease. For these points of pressure two padded ribbons of sheet metal cross the dorsum and a padded transverse curved piece is placed against the hollow of the palm. The palmar piece is of wire rod .082 inch in thickness and is turned up at each end dorsally until it is opposite the center of motion or imaginary axle of the proximal finger joints. Here it is looped on itself for a pivot and prolonged to the dorsum of the hand to be integrated there with the transverse metal ribbon. The distal metal ribbon over the proximal finger segments is soldered at each end to two such short wires, each of which ends in a loop linked to a loop of the crosspiece wire.

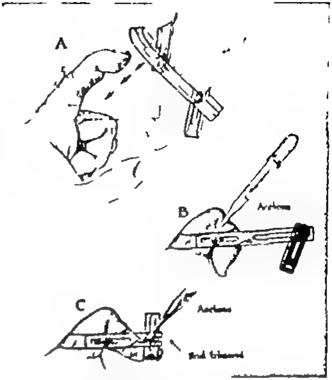
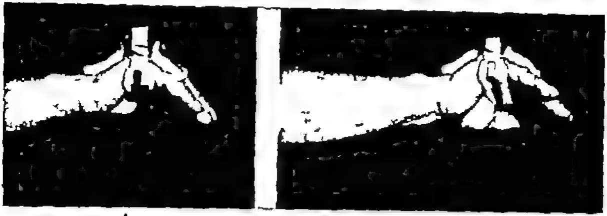


FIG. 91. Splint for rupture of terminal insertion of extensor tendon of a finger to flex the middle and extend the distal joint. This ingenious splint of plastic was devised by Jos. D. Godfrey of Buffalo, N. Y.

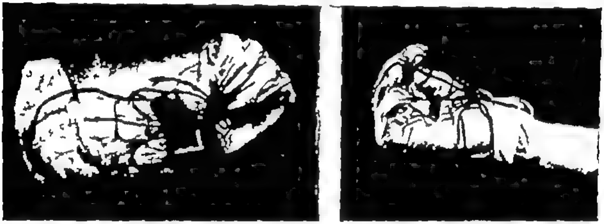
The hinge of the splint is in the axis of the proximal finger joints. The wire rods, to reach from here to the dorsal plane of the hand where they fasten to the cross ribbons, must angulate there to conform to the dorsal contour. Motor power is furnished by a rubber band over the end of the wires at each side as shown in Figs. 96A and 96B. The wires along the dorsum of the hand are prolonged proximally and bent volarward to end in hooks at the plane of the palm to keep the rubber bands from pressing the skin and to give better leverage.

The splint will pull through from the straight position of the metacarpophalangeal joints to the completely flexed one. This splint is simple, cheap and easy to make of wire, sheet metal, felt and rubber bands. It is light, comfortable, goes through the coat sleeve, and is on the hand



A B

FIG. 92A. (A) Metacarpal splint to force proximal finger joints into flexion. *Precedes use of the glove.*
(B) The bar is curved to fit the metacarpal arch.
The knuckle bender splint is preferable



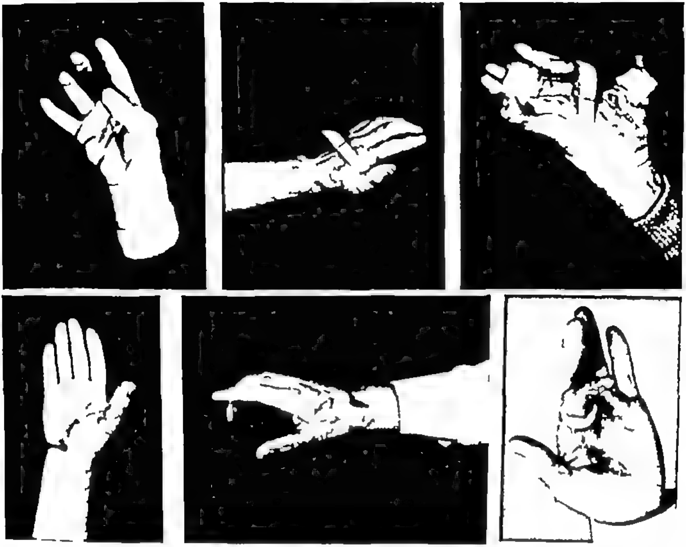
A B

FIG. 92B Use of glove to draw fingers into flexion by slow mild, steady traction. For use after metacarpal splint has started flexion in the proximal finger joints.
(A and B) Showing how cords from each pair of fingers loop about buckle on web belt which is riveted to the glove and tied to each other under proper tension.

A B

FIG. 92C. (A) Web belts and buckles used to draw finger joints into flexion by slow mild, continuous traction. Various other ways of applying straps can be used.
(B) A rod prevents the strap from slipping off.

A B C



D E F

Fig. 93 Splints for the thumb

(A) To maintain opposition adhesive tape is looped over a pad on the proximal joint and made to pull the thumb toward the pisiform bone and also rotate it in pronation. One arm of the tape is fastened around the hand the other around the forearm.

(B) To keep the thumb adducted after a strain of the adductor insertion. A web belt and buckle is used as a figure-of-eight.

(C) To counteract a contracture the thumb may be spread from a digit by holding against them with web belt and buckle a strip of metal terminated by two flat, curved, padded end pieces to press the respective digits

(D and E) A simple thumb protector is made from a cone of celluloid fastened to itself by acetone drilled with a hot wire and kept in place by a cord about the wrist.

(F) Finger and palm splint of vinyl acetate.

only and does not interfere with the use of the hand

To make it a 17 inch piece of wire is bent for cross piece, pivot and sidebars Two short pieces are linked to it The two cross ribbons are crimped and soldered to these wires ¾ inch from the pivots The wires are bent so the ribbons conform to the con tour of the back of the hand. Felt is riveted to the sheet metal ribbons and sewed about the crossbar The rubber bands are Eberhard Faber size 31

The usual mistake in making this splint is not to have the pivots in the exact line of axis of the metacarpophalangeal joints This axis runs through the centers of the heads of the metacarpals The wires, then to gain a position on a level with the dorsal surface of the hand, must bend as they reach the cross ribbons

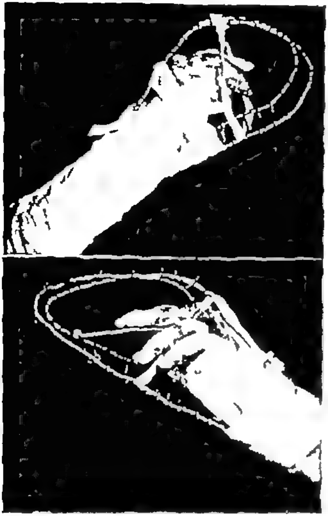
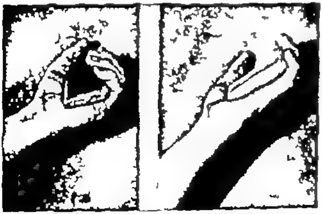


FIG 94 (*Top*) Air dressing by using a loop of Cramer wire incorporated in plaster of paris. The whole is covered with gauze. (*Bottom*) Aluminum extension to steady a fracture.



A B

FIG. 95 To exercise newly repaired tendons and stiff joints a rounded rectangular block of wood furnishes the right fulcrum on which the middle finger joint (A) and the distal one (B) can act. A rubber ball exercises mostly the proximal joints.

A knuckle bender of smaller size is useful to draw the middle finger joints into flexion.

A combination of knuckle bender and Oppenheimer splint is made for the position of nonfunction to draw the wrist into dorsiflexion, proximal finger joints into flexion, thumb to opposition and distal two finger joints into extension.

Still another knuckle bender is made in reverse to straighten the proximal finger joints.

KNUCKLE BENDER SPLINT FOR PARALYTIC CLAWHAND The knuckle bender splint is excellent for correcting the clawhand, flat palm, thumb at the side deformity from combined median and ulnar palsy It flexes the proximal finger joints to hold the thumb in opposition, it is only necessary to lift the rubber band on the thumb side over the thumb so it will press on the dorsum holding the thumb forward. To oppose the thumb more positively against joint resistance, a leather loop about the base of the thumb is pulled by a rubber band towards the rear wire hook on the opposite side. About this it is looped and drawn forward to hook over the distal projecting wire end If the joints are not rigid, thin druggist rubber bands on the splint will suffice to substitute for muscle balance

To extend the middle finger joints of clawhand, an outrigger of wire bent into a U is made to slip over the sheet metal ribbon on the back of the fingers Over the crossbar of this U is a tube roller Leather cuffs over the finger ends are pulled by rubber bands over the roller The bands are fastened to drill holes in the sheet metal over the fingers The splint will then flex the proximal finger joints and extend their distal two It will draw the thumb into opposition as explained in the third paragraph below The metacarpal arch is curved by the pressure of the curved palmar piece. It places the hand in the position into which the intrinsic muscles should place it.

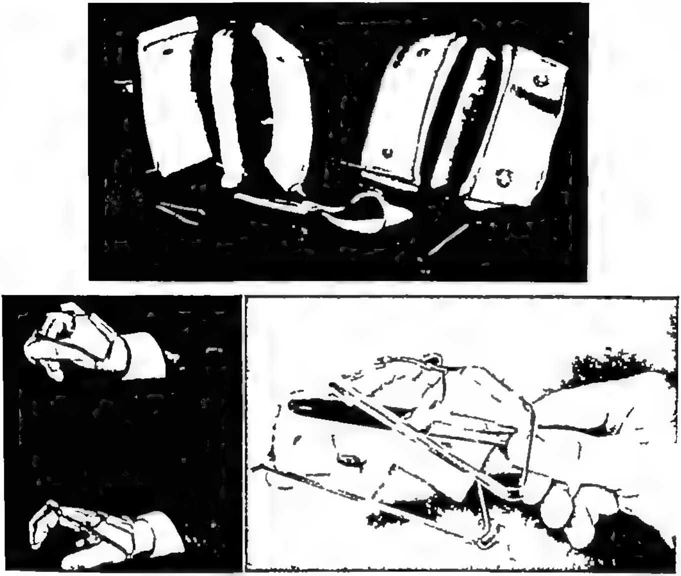


Fig. 96A. Knuckle bender splint to draw proximal finger joints into flexion. This light, simple splint carries the motion through. There are three points of pressure, well padded and motivated by rubber bands

(A) (*Lower*) Proximal finger joints extended.
(*Upper*) Proximal finger joints drawn into flexion.

Note Placing rubber on back of thumb draws it into opposition. A leather loop on a rubber band over the rear hook will draw the thumb firmly into opposition (Fig. 96B)

(B) Holding splint open with fountain pen.

When a hand and wrist are in the complete position of nonfunction, the knuckle bender, combined with a spring wrist cock up splint, will correct the position of all of the joints at once, especially the key joint to the deformity the wrist.

Web Strap Method Even more flexion can later be gained by strapping the fingers in flexion by a long, narrow web belt and buckle which encircles the fingers in various directions and holds in place on the hand by a figure-of-eight turn around the wrist (Fig 92C)

To Hold Thumb Extended. The thumb can be held in extension by a supporting outrigger rod and gutter riveted to the forearm piece of the cock up splint A flexed thumb can be gradually drawn into extension by applying a padded flat spring looped over the end of the thumb and fastened with adhesive straps The spring may end at the wrist or be fastened well up the forearm for good leverage A spring is usually bent so the metacarpophalangeal joint is used as the fulcrum. This may be used in conjunction with a cock up splint.

To Hold Thumb in Opposition. The thumb may be held in the position of opposition by looping a one-half inch adhesive tape around the padded dorsum of the distal end of the metacarpal and drawing the thumb toward the pisiform bone. The two arms of adhesive tape are then continued, one around the back of the hand and the other around the back of the forearm. The resultant is in line with the pisiform. This strapping aids in correcting flat hand. Another method is to use the elastic band and leather cuff for opposition with the knuckle bender splint (Fig 96B), looping the rubber around the proximal hook and over the distal projecting wire.

To Hold Thumb in Adduction. ' hold the thumb near the hand, as af strain of the short adductor muscles, a n row web belt and buckle encircles the he of the first metacarpal, crosses itself in the depth of the first interdigital cleft, and loops around the ulnar border of the hand

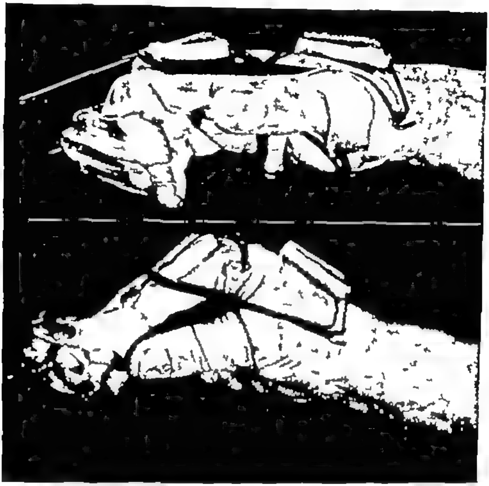


FIG. 96B Elastic knuckle bender splint to restore muscle balance and position of function in combined median and ulnar palsy This flexes proximal finger joints, draws thumb into opposition, and, by detachable wire outrigger with metal tubing roller corrects position of claw-finger (*Upper*) Position of intrinsic muscle, minus (*Lower*) Position of intrinsic muscle, plus.

Celluloid Cone for Thumb. To immobilize or protect the thumb as a whole, a cone made out of sheet celluloid sealed closed in its distal third (*using acetone*) is made to encircle the thumb and cover the dorsal and volar parts of the thenar eminence. Fastened to two holes in its proximal part, two cords are tied about the wrist to hold the cone in place (Fig 93)

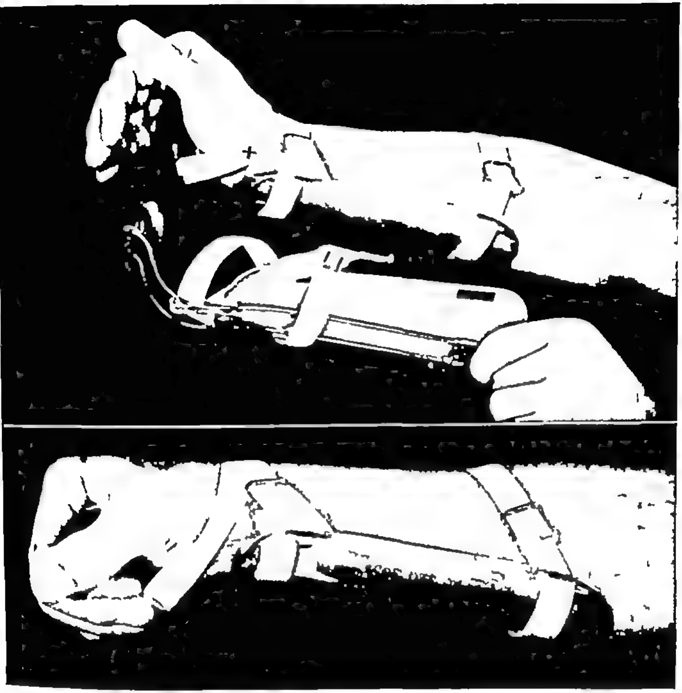


FIG. 96C. Spring cock up splints made of flat blued spring size .045 x ⅝ inch or of a loop of piano wire size .015 inch. This splint gradually persuades the wrist to assume a position of dorsiflexion. An oblique strap (X) through the chamber in the neck piece and looped over the back of the wrist is essential to hold the splint in place. Spring splints exercise.
(*Upper*) Dorsiflexion (*Lower*) Flexion.

Splints for Paralyses

In paralysis the joints should not be held in overcorrection, nor should the paralyzed muscles be rendered unduly long from stretching The hand should be kept in the position of function, but given plenty of freedom of motion so it will keep healthy and not be hampered in occupational therapy No joint should be splinted that does not need it. Only enough elastic correction should be made, and no more, to correct exactly for the lack of muscle balance Rigid splints for this are out. Splinting for paralysis when overdone abuses the principle and wrecks hands.

For Radial Palsy Only the wrist, proximal finger joints and the base of the thumb should be supported in extension Two splints are useful, the Oppenheimer and

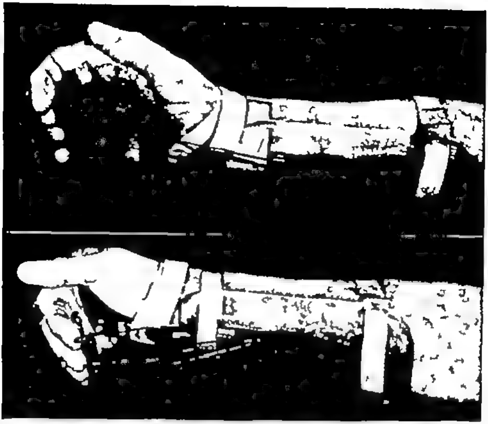


FIG. 96D Spring cock up splint with attachable outrigger to draw proximal finger joints into flexion. As the joints flex more the rubber bands are connected directly to the hook in the belly of the splint.
(*Upper*) Dorsiflexion wrist and extension of proximal finger joints (*Lower*) Flexion wrist and flexion of proximal finger joints.

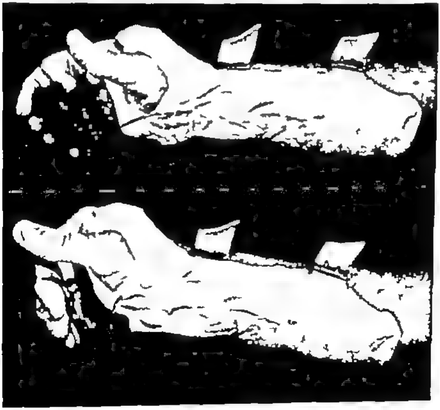
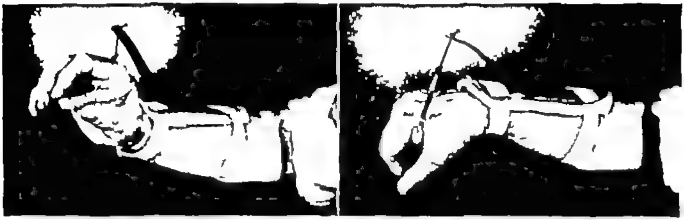


FIG. 96E. Splint to draw proximal finger joints into flexion. Plaster-of-paris method. Leather loops pull by rubber bands over a roller (metal tubing) on a wire outrigger As the joints bend, the wire outrigger is bent to continue the flexion. The rubbers exercise the fingers.

FIG. 96F Plaster-of-paris splint with wire outrigger to extend the distal two joints of the fingers in claw hand To prevent the proximal finger joints hyperextending a felt pad is placed between the cast and the proximal segments of the fingers

FIG. 96G Spring suspension cock up splint. (*Left*) Dorsiflexion (*Right*) Flexion.



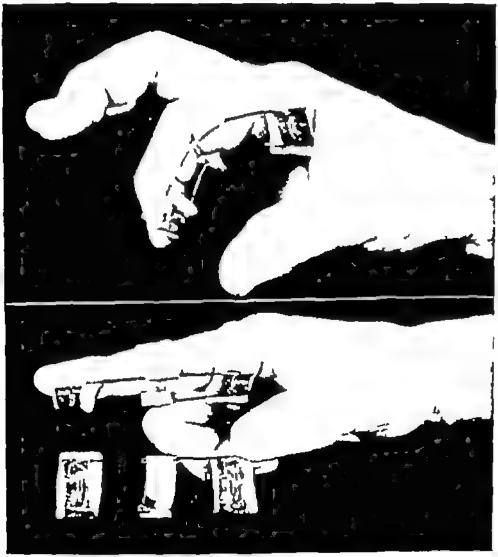


FIG. 96H. Spring safety-pin splint to force contracted finger into extension. Size .033 inch wire furnishes enough spring to exercise the finger

that suspension splint described by F B Thomas.

OPPENHEIMER SPLINT The following includes desirable modifications This is made of light spring wire, not stronger than

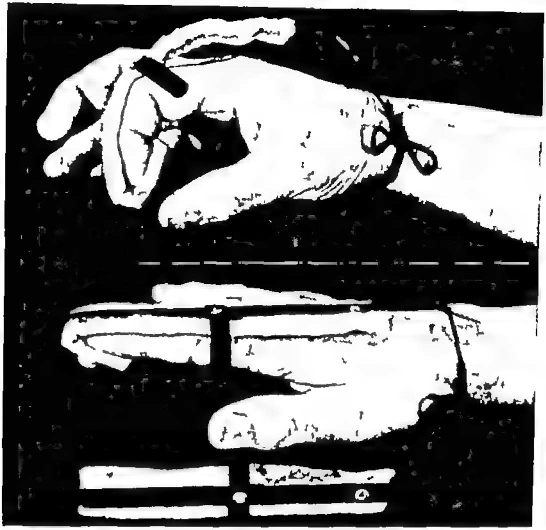


FIG. 961 Clock spring splint to extend the finger gradually ; Size .02 x $^{19}/_{64}$ inch. (*Upper*) Flexion (*Lower*) Extension.

from 067 to 075 inch in diameter It is bent into a rectangle open proximally, the distal crosspiece being curved to fit across under the distal plica in the palm where it will support the proximal finger joints. At the proximal end, a volar cross ribbon of metal bridges between the wires and curves under the forearm Just above the wrist, a web belt and buckle loops about each wire and crosses over the dorsum. At the wrist each wire is made into an open loop for extra spring and here the splint is bent backwards to hold the wrist in dorsiflexion. It is necessary to place another web belt and buckle through these two loops and around the dorsum of the wrist or else the splint will not remain in place. Brazed to one wire is a short very light spring (033 inch) wire to act as outrigger to draw the base of the thumb into extension. A leather cuff loops about the thumb and pulls from the outrigger by a rubber band. The old model with the wire ring holds the thumb too rigidly, and in it the splint wires were too stiff

THE SUSPENSION SPLINT FOR RADIAL PALSY (modified from F Bryan Thomas) The forearm piece may be a plaster slab or a padded hammered piece of duralumin (hollowed on each side to allow for the prominence of the head of the ulna) It

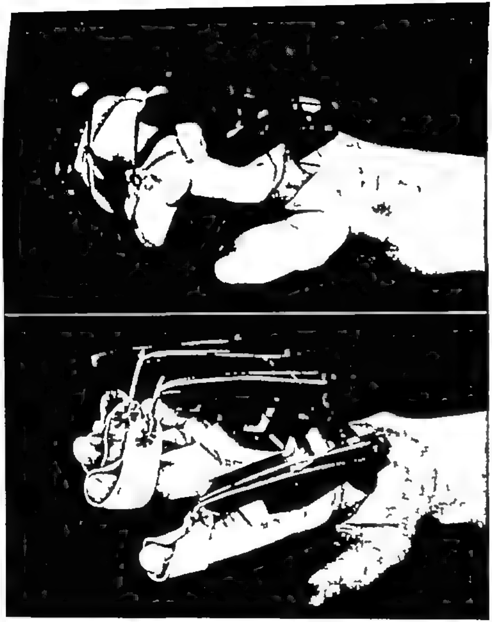


FIG. 96J Splint to extend distal two finger joints. Made of clock spring and rubber bands, the fulcrum is over the proximal finger segments. The splint is comfortable and encourages use and exercise of hand. Freedom of motion shown. (Designed by Sgt. S L. Cravath and Lt. Col Donald R Pratt Dibble General Hospital, U S A.)

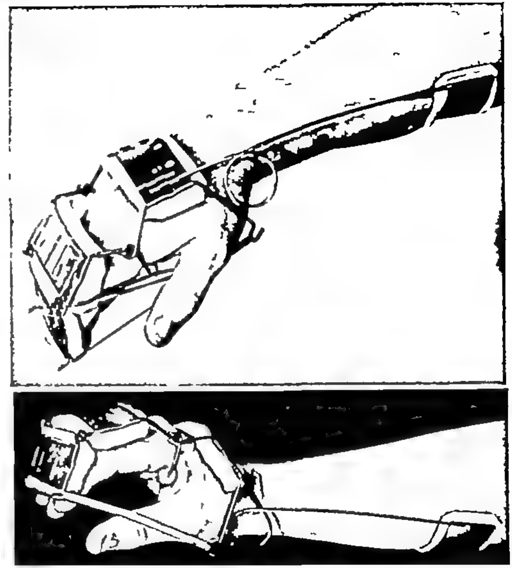


FIG. 96K Combination knuckle bender and Oppenheimer splint with attachment to flex middle finger joints. Purpose To place hand in position of function to dorsiflex wrist, to flex proximal and middle finger joints and to oppose thumb The Oppenheimer splint and that to flex the middle finger joints are made to attach to the knucklebender

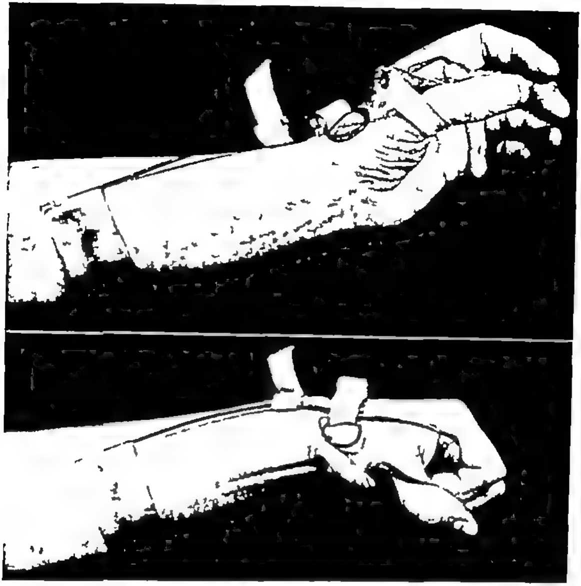


FIG. 96L. Spring splint for radial palsy modified from Oppenheimer in that the thumb is held in a leather cuff by a light, 033 inch spring steel wire, and the main wires are as light as 069 inch. This restores muscle balance in position of function and allows hand to be free to work.

ends at the wrist and is strapped to the forearm From the forearm piece extend two light spring wires, 063 inch in diameter for the hand and 056 inch in diameter for the thumb Each terminates in a loop from which a rubber band extends for the hand, to a curved padded crosspiece (rubber over metal rod) and for the base of the thumb, to a leather cuff One wire arches over the hand supporting the bases of the fingers and also the wrist in extension The rubber band is through the apex of the second in terdigital cleft, and the cross rod supports along the plica of the palm The other wire arches in a plane at right angles to the first to give slight extension to the base of t thumb The wires should not arch so i from the hand to prevent passing throu a coat sleeve. This splint does all that necessary and gives remarkable freedc of motion If the wires emerge from t center and there is a bilateral hollow for t ulnar head, the splint is interchangeable f either hand.

Splint for Combined Median and U nar Palsy The splint pictured in Fig ı can be used, but it is preferable to use tl principle of elastic correction as furnishe by the knuckle bender splint, Fig 96B

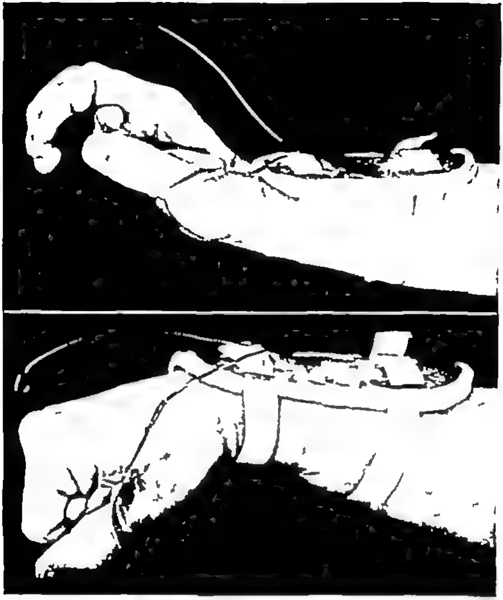


FIG. 96M. Spring wire suspension splint of Thomas for radial palsy modified by using lighter spring wire for the thumb .045 inch, and .075 inch for the wrist. The crossbar should be arched and at the plica of the palm. This splint gives perfect freedom of action and perfect muscle balance.

FIG. 96N Miniature knuckle bender to flex middle finger joint.

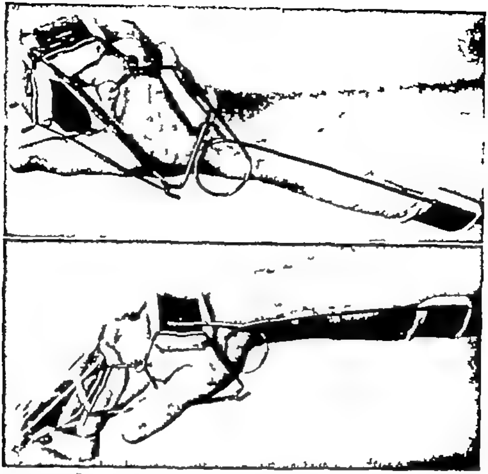


FIG. 96O Combination of knuckle bender to flex the proximal finger joints, an outrigger to extend the distal two finger joints, and an Oppenheimer splint to dorsiflex the wrist. The object is to place the hand in the position of function. Extra segment is shown at left

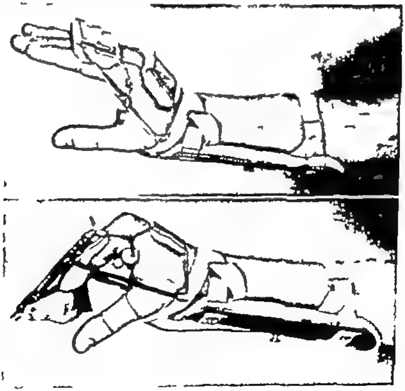


FIG. 96P Combination of knuckle bender splint to flex the proximal finger joints and oppose the thumb, an outrigger to extend the distal two finger joints and a spring cockup splint to dorsiflex the wrist. The object is to bring the hand into the position of function.

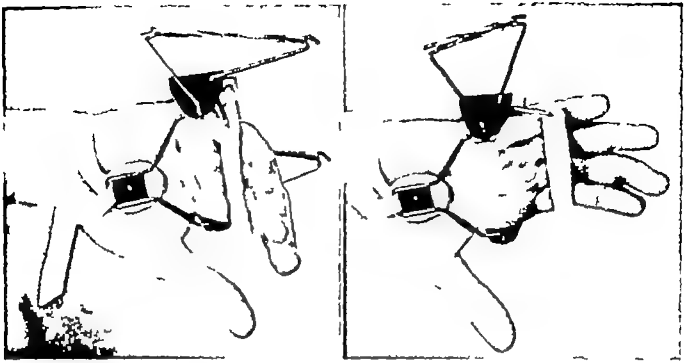


Fig. 96Q Reverse knuckle bender splint to extend the proximal finger joints in ischemic contracture local in the hand

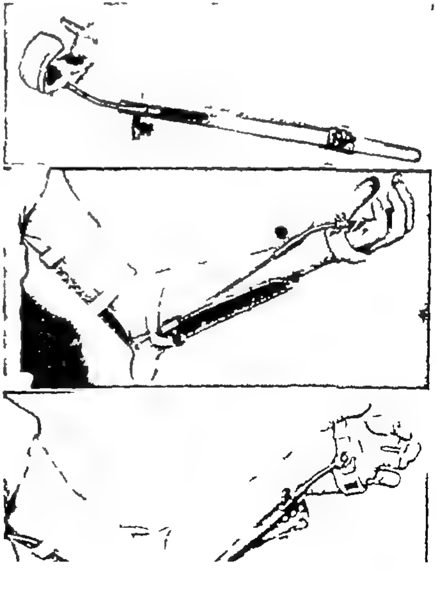


Fig. 96R. Spring splint to twist the forearm into supination. Will also pronate. The unit is clamped to a standard elbow splint and adjusted by set screw on axle so that the twisted flat spring will supinate the hand to the desired degree.

Splint for Ulnar Palsy For this all that is necessary is to furnish elastic flexion to the proximal joints of the ring and little fingers by means of leather loops and light rubber bands running to a wristband

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5

Skin and Flexion Contractures

REPLACEMENT OF SCAR BY GOOD TISSUE

Most severe open wounds or infections on healing show extensive *cicatrix of skin* and deeper tissues. This contracts, drawing to itself the skin from all directions, as well as the *deeper parts. Nutrition is hampered*, until the limb is hidebound and its deeper structures, *lymph, blood vessels*, and nerves are *strangulated by deep cicatrix.* The surface scar is avascular, hard, adherent, and *easily injured*. Its center may break down from lack of blood supply.

Nutrition must be restored by liberation *from cicatrix*. Cicatrix is avascular, fibrous infiltration that contracts, binding all structures in its grasp both deep and superficial. Movable structures *are bound, and life lines*, such as blood vessels, lymph vessels and *nerves are strangled. Such a cicatrix impoverishes the hand.* It may infiltrate the whole hand or be along its only source of supply, the forearm or the narrow wrist. A cicatrix on only one side *of a limb* so draws to itself both deeply and about the surface that it acts as a veritable girdle, the source of supply being longitudinal. The two-thirds of circumference that is of good skin will be tight. As in repair of deep structures throughout the body, this cicatrix should first be excised and replaced by good skin.

It would be folly to incise through such tissue to repair the deeper structures. The *skin of the scar* could not again be drawn together, and if it could it would break down *from ischemic necrosis, exposing the* vulnerable tissues beneath to long lasting, sloughing infection. No deeper tissues can move through or under cicatrix. Bones will not have sufficient blood supply to unite and the nutrition of the hand will not be improved.

Before attempting repair of deep parts, the cicatrix, *both deep and superficial*, must first be completely excised down to normal vascular tissue. The borders of the surrounding skin should be undermined, allowing the taut skin to retract freely. New good material is then needed to fill in the *defect. This may be furnished by the sliding* skin flap or by the pedicle skin graft which provides both skin and subcutaneous tissue. Free grafts of skin will not suffice *when deeper* structures *are* involved and the bed is cicatricial, or of tendon, ligament or bone. The limb should be decompressed and freed from any binding so that all will be warm, soft and pliable, and muscles will roll freely under yielding skin. Superabundant blood supply is essential for reconstruction of all tissues, tendons, nerves, joints or obtaining union in bone. This is absent in cicatrix, but by *liberating tissue and covering by good* pedicle skin, the blood supply is restored.

At the next operation for repair of the deep structures, *the deep cicatrix is dissected* out and excised en bloc, *freeing* the deep structures. The effect on the hand

is liberation from binding cicatrix so it breathes and thrives again, and nutrition is restored, improving its every structure This viewpoint is to decry the mere removal and replacement by pedicle of a surface cicatrix with no regard to excising the deep cicatrix with structures that should not be severed

Regard should be held for the creases and folds of the skin *Unfortunately, it is still urgent to warn against making the all too-prevalent pernicious median longitudinal incisions in the hand and incisions which*

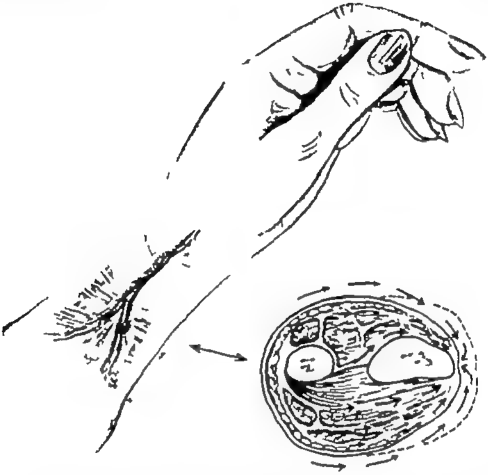

FIG. 97 A cicatrix on one side of a limb strangles that complete segment of the limb The cicatrix includes skin and the various layers of deep fascia and tissues. As it contracts all structures are drawn towards the center of the cicatrix with a strangling effect of the whole segment. The source of supplies to the hand is longitudinal along the limb Therefore a cicatrix on one side of the limb may impoverish the hand. Excision of cicatrix, undermining of skin borders and replacement by pedicle skin graft restores nutrition to the hand.

from between the deep structures or thoroughly freeing skin borders

INCISIONS

Before incising a hand, due consideration over the choice of incision well repays In cisions made thoughtlessly may damage, because the hand is unusually mobile, thus leading to contractures if incisions are wrongly placed, and because it is packed

cross natural creases at a right angle or nearly so These lead to keloids and contractures, due to the irritation of intermittent traction and compression at each movement. Such incisions do harm whether they are in hand or wrist Along the volar aspect of a finger, the resulting scar draws the finger into flexion The cut pulleys allow the tendons to bow across the finger on flexion, the special gliding surfaces of the pulleys have been cut through, and a long

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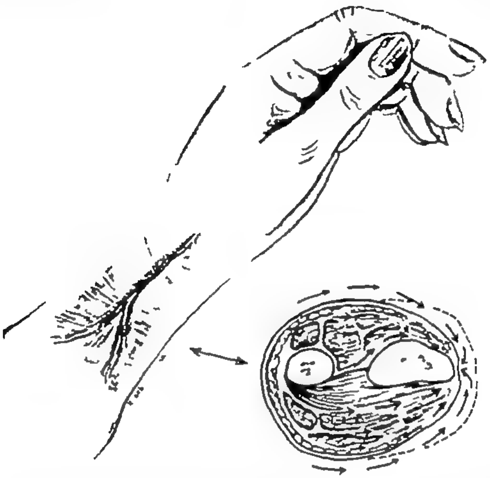

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INCISIONS
KELOIDS
FLEXION CONTRACTURES
PEDICLE SKIN GRAFTS
FREE SKIN GRAFTS
DUPUYTREN'S CONTRACTURE
VOLKMANN'S ISCHEMIC CONTRACTURE

REPLACEMENT OF SCAR BY GOOD TISSUE

Most severe open wounds or infections on healing show extensive cicatrix of skin and deeper tissues. This contracts, drawing to itself the skin from all directions, as well as the deeper parts. Nutrition is hampered, until the limb is hidebound and its deeper structures, lymph, blood vessels, and *nerves are strangulated by deep cicatrix.* The surface scar is avascular, hard, adherent, and easily injured. Its center may break down from lack of blood supply.

Nutrition must be restored by liberation from cicatrix. Cicatrix is avascular, fibrous infiltration that contracts, binding all structures in its grasp both deep and superficial. Movable structures are bound, and life lines, such as blood vessels, lymph vessels and nerves are strangled. Such a cicatrix impoverishes the hand. It may infiltrate the whole hand or be along its only source of supply, the forearm or the narrow wrist. A cicatrix on only one side of a limb so draws to itself both deeply and about the surface that it acts as a veritable girdle, the source of supply being longitudinal. The two-thirds of circumference that is of good skin will be tight. As in repair of deep structures throughout the body this cicatrix should first be excised and replaced by good skin.

It would be folly to incise through such tissue to repair the deeper structures. The skin of the scar could not again be drawn together, and if it could it would b down from ischemic necrosis, exposing vulnerable tissues beneath to long las sloughing infection. No deeper tissues *move through or under cicatrix.* Bones not have sufficient blood supply to u and the nutrition of the hand will no improved.

Before attempting repair of deep p the cicatrix, both deep and superficial, r first be completely excised down to nor vascular tissue. The borders of the *rounding skin* should be undermined, all ing the taut skin to retract freely. I good material is then needed to fill in defect. This may be furnished by the s ing skin flap or by the pedicle skin g which provides both skin and subcutane tissue. Free grafts of skin will not sui when deeper structures are involved : *the bed is cicatricial, or of tendon, ligam* or bone. The limb should be decompres and freed from any binding so that all v be warm, soft and pliable, and muscles v roll freely under yielding skin. Sup abundant blood supply is essential for construction of all tissues, tendons, nerv joints or obtaining union in bone. This *absent in cicatrix, but by* liberating tis and covering by good pedicle skin, the blo supply is restored.

At the next operation for repair of t deep structures the deep cicatrix is d sected out and excised en bloc, freeing t deep structures. The effect on the ha

is liberation from binding cicatrix so it breathes and thrives again, and nutrition is restored, improving its every structure. This viewpoint is to decry the mere removal and replacement by pedicle of a surface cicatrix with no regard to excising the deep cicatrix with structures that should not be severed

Regard should be held for the creases and folds of the skin *Unfortunately, it is still* urgent to warn against making the all too-prevalent pernicious median longitudinal incisions in the hand and incisions which

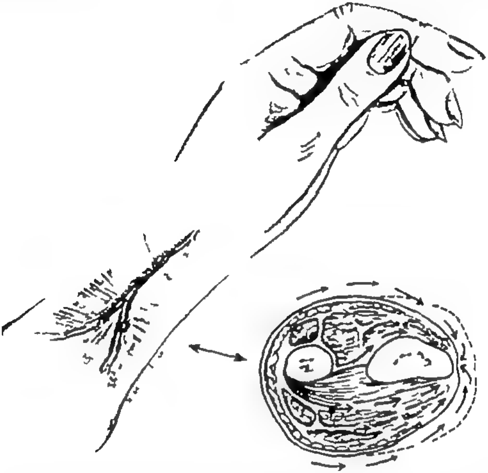


FIG. 97 A cicatrix on one side of a limb strangles that complete segment of the limb The cicatrix includes skin and the various layers of deep fascia and tissues. As it contracts all structures are drawn towards the center of the cicatrix with a strangling effect of the whole segment. The source of supplies to the hand is longitudinal along the limb Therefore a cicatrix on one side of the limb may impoverish the hand. Excision of cicatrix, undermining of skin borders and replacement by pedicle skin graft restores nutrition to the hand.

from between the deep structures or thoroughly freeing skin borders.

INCISIONS

Before incising a hand, due consideration over the choice of incision well repays In cisions made thoughtlessly may damage, because the hand is unusually mobile thus leading to contractures if incisions are wrongly placed, and because it is packed cross natural creases at a right angle or nearly so These lead to keloids and contractures, due to the irritation of intermittent traction and compression at each movement. Such incisions do harm whether they are in hand or wrist. Along the volar aspect of a finger, the resulting scar draws the finger into flexion. The cut pulleys allow the tendons to bow across the finger on flexion, the special gliding surfaces of the pulleys have been cut through, and a long

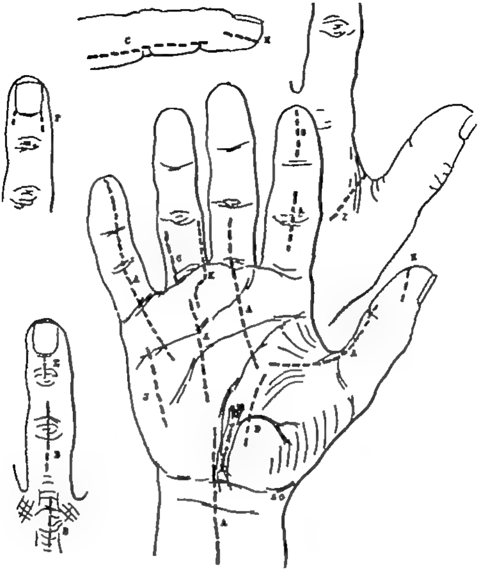


FIG. 98A. A chart of pernicious or incorrect incisions in the hand, any of which will do harm.

(A) Median longitudinal incisions which cross flexion creases at right angles and result in flexion contractures. These are prevalent but pernicious.

(B) Median incision on dorsum of finger which later leaves a scar that contracts and hinders flexion of the finger. When present, it is impossible to fashion a proper skin flap under which to repair the extensor tendon.

(C) Anterolateral incision in finger which is directly over and endangers the vessels and nerve. It is the usual one pictured for draining tendon sheaths, but should instead be mid-lateral.

(D) Incision which thoughtlessly severs the motor thenar nerve and so robs the thumb of the power of opposition.

(E) Median longitudinal incision through matrix will produce a ridged nail.

(F) Incisions for paronychia often pictured but erroneous, as they do not drain the bottoms of the clefts formed by the borders of the base of the nail which curve strongly forward.

(G) Median longitudinal incision in pulp for drainage of a felon. It will not drain as due to cleavage planes the pus progresses in spite of it and points dorsilaterally. Also the scar resulting is in the tactile surface.

(H) Alligator mouth incision wrongly placed too far anteriorly which leaves a scar in the tactile surface.

(I) Incision across a web injures the web which itself has a function of complicated foldings to allow for movements of thumb.

(J) Incision often made for drainage of pus in sheath of tendon to little finger. The tendons, however, converge sharply in palm to pass between the ridge of the trapezium and the unciform process of the unciform bone.

(K) Incision continuous from finger to palm severs nerve, thus rendering half of finger permanently anaesthetic. (Courtesy Jour. Bone and Joint Surg., 14 Jan., 1932.)

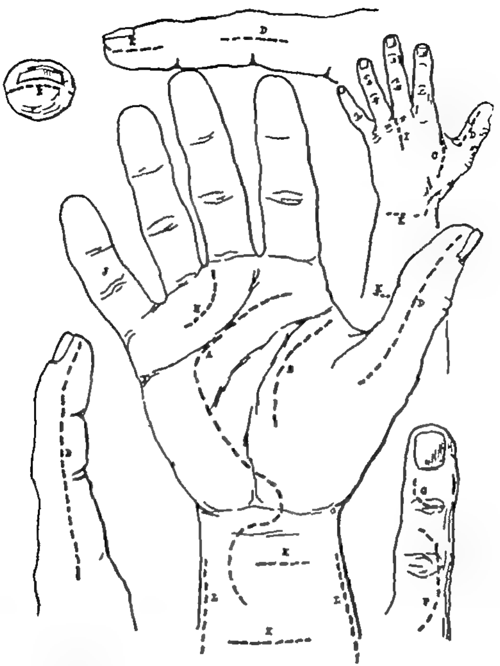


Fig. 98B A chart of advisable or correct incisions in the hand which will afford access and will not cause disability

(A) Incision opening palm or draining middle palmar space parallels flexion creases, exposes by triangular flap, enters between median and ulnar nerve supplies, and may be extended through ulnar side of carpal ligament up forearm. Curve crossing creases in wrist avoids contracture.

(B) Drainage for thenar space, parallels thenar crease. Must not sever the thenar motor nerve. Pedicles between it and palmar incision must be wide enough to nourish intermediate skin.

(C) Usual drainage for thenar space. Should be radial to interosseus muscle and not sever radial artery in cleft.

(D) Mid-lateral incisions in digits, spare nerves and vessels and do not cause flexion contractures

(E) Drainage for pulp abscess, posterior to tactile surface. Should sever the vertical fat columns and not cause tenosynovitis by nicking sheath of flexor tendon.

(F) Flap exposure to not overlie extensor tendons.

(G) Exposure of insertion of extensor tendon.

(H and I) Drainage of collar button abscess. Avoid volar nerve.

(J) Flap drainage of subcutaneous abscess. One arm is median to nerve and the other blocks upward extension of infection.

(K) Transverse incisions parallel wrinkles, thus avoiding conspicuous keloid formation.

(L) Drainage for quadrilateral space in forearm. Made anterior to bone and radial nerve and posterior to dorsal branch of ulnar nerve. (Courtesy Jour Bone and Joint Surg., 14 Jan., 1932)

Fig. 99 Flexion contracture from the pernicious median longitudinal incision.

length of adhesions binds the tendon. In the finger pulp, median incisions will not drain infections and scar is left on the tactile surface Incisions through the matrix result in a split and ridged nail On the dorsum of a finger if the scar is median it overlies the tendon, resulting in adhesions. The scar limits the flexion and makes it impossible later to use a skin flap incision for repair of the tendons The hand in motion demonstrates that there are, in the skin, certain directions in which there is push and pull *Incisions coinciding with these may become irritated to thick contracting scars.*

Elastic and connective tissue fibers in the derma are arranged parallel to the flexion creases. Therefore, a scar across a flexion crease broadens due to traction by these fibers

Lines of Langer in the main conform to *the flexion creases at the joints of the body* In the palm, sole, and a few other places, however, they do not. In planning incisions, therefore the true way is to be guided by the flexion creases as we see them at the time rather than to depend *on memorized* lines of Langer Incisions should parallel flexion creases

A finger should be opened by midlateral incisions, not anterolateral as so often pictured, for these are exactly over the nerves and vessels. Midlateral incisions, being just behind the three volar creases, are not subject to intermittent compression and tension and so may become invisible. The more volar or dorsal on the finger, the more is the movement of the scar In the palm there are three major folds which, if crossed, lead to contractures. The contents *of a palm may be completely exposed by an* L-shaped incision paralleling the distal crease and turning in an obtuse angle up the immobile heel of the palm to the carpus. Incisions on back or front of the wrist will become *invisible if* they conform to the creases, but make ugly keloids if they cross them. The cross incision may be prolonged *longitudinally up the limb* at one end and down it at the other, giving a wide double-flap exposure This is a good way of uncovering tissues beneath a transverse or diagonal scar or laceration, instead of making the usual longitudinal one crossing it at the center An L incision heals better than an λ, Y, or T It is rarely necessary to *make a cross-extension over the volar aspect* of a finger like an L On the dorsum of a finger, the incision may extend longitudinally down one side and then cross abruptly over and continue down the other side. *In the pulp, a lateral or alligator* mouth incision is advisable, made posterior to the tactile surface. When incisions must *cross creases they should curve or zigzag* to prevent contraction. In this way, the structures of the palm and forearm can be laid open in one incision, being careful to enter between the two nerve distributions *—the median and ulnar along the fourth* ray

Regard when choosing an incision should also be had for the deeper structures. No tiny nerves should be cut, such as the volar nerves of the *digits* and *especially* the *motor* thenar branch of the median nerve for opposition of the thumb, or the motor one of the ulnar on which function of the intrinsic muscles depends. Even the nerve twigs to the lumbricals should be preserved. In making a transverse incision on the dorsum of the wrist the skin on each side should be

FIG. 100 Case M L. Flexion contracture due to the pernicious median longitudinal incisions used for the repair of the tendons of two fingers.

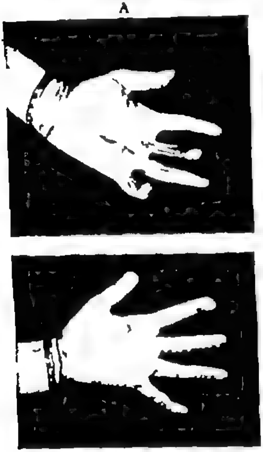


FIG. 101 Case R. T Flexion contractures in ring and little fingers from falling in fireplace at age of ten months. At the age of 29 the keloids were excised, grafting whole skin in their place, while the hand was kept immobile on a spreading metal splint.

(A and B) Showing pre- and post operative conditions.

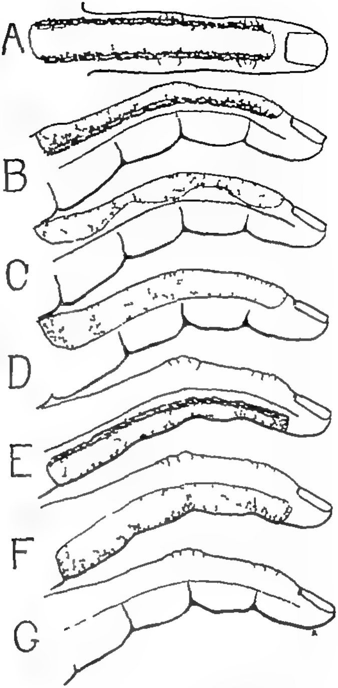


FIG. 102 The only line along a finger that is not subjected to push and pull is the midlateral. Incisions and borders of free or pedicle grafts, if made midlateral will be inconspicuous.

(A and B) Dorsal skin graft borders are dorsal to midlateral line as drawn on each finger so from irritation of 'push and pull are keloidlike. Compare with D

(C) If a nonmidlateral scar is made wavy it will be less conspicuous.

(D) Properly sized skin graft. Enough normal skin has been cut away to allow the graft borders to be midlateral.

(E) Volar skin graft borders are volar to the midlateral line and hence form keloid.

(F) Properly sized volar skin graft to make the borders midlateral.

(G) Midlateral incision becomes inconspicuous. Flexion creases terminate at midlateral line where there is no push and pull.

undermined freely, keeping rather superficial in the superficial fascia because the branches of the radial nerve, as also the other cutaneous nerves in the forearm and

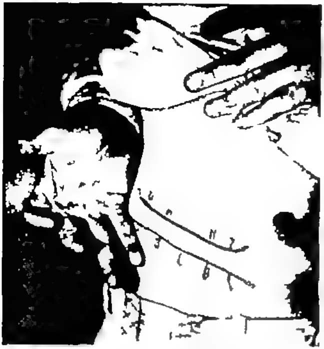


FIG 103 To relieve this traumatic flexion contracture new pedicled skin is needed to fill the defect after excision of the scar

hand, lie deep in the superficial fascia. Utilizing wide undermining, a longitudinal incision through this fascia then carries one into the deeper structures An incision should not overlie a tendon or the latter will be bound by a length of adhesions All annular bands or pulleys should, if opened, be slit through at one side, instead of through their central gliding surface Incisions should be remote from tendon sutures or other repaired parts that might become adherent to the scar or exposed if the incision should separate. When possible, repaired parts should be separate from each other to reduce the local burden of healing and to prevent adhesions

KELOIDS

Keloids are composed of thick cicatricial tissue covered by a thin layer of epidermis and contain some sweat and sebaceous glands They are the result of overhealing instead of healing to the surface and stopping, the tissues continue to pile up well above the surface level and widely The richness of blood vessels and luxuriant growth give the red color After a year and a half the cicatrix usually softens, lowers to the normal level, and whitens. Keloids usually occur in dark races, though they are often seen in light ones, even when there is white skin and red hair Burns are prone to form keloids, evidently from the tissue that has been partially burned but has recovered.

In the absence of the above causes—certain individuals, races—it is within the surgeon's power to cause or prevent keloids in the hands and elsewhere.

Unfortunately, the cosmetic appearance is often given too little consideration This is important even in hands. Much depends on the direction in which the incision is made in determining whether the resultant scar will be practically invisible or will be a conspicuous keloid contracture. This is dependent on whether the incision follows the folds or natural wrinkles in the skin or crosses them at a right angle or even obliquely

Keloids and hypertrophic scar contracture, which intergrade, form in response to postoperative irritation, either from something rubbing upon them or from the irritation of intermittent tension and compression incurred when folds or creases of the skin in the normal motion of the hand are continually opening and closing. This is often demonstrated in an L-shaped scar, the line of the L following the creases will be practically invisible, while the other line will be conspicuous, even to the degree of a contracting thick keloid This principle, which applies throughout the body, is usually overlooked, as evidenced for instance by the usual oblique direction of the McBurney and inguinal hernia scars, which could have been practically invisible if made transversely

Deep cicatricial tissue reacts just as does skin in its response to intermittent tension When a deep cicatrix spans a joint, so that it is pulled each time the joint straightens, it forms in the line of tension a firm, thick

contracting cord of scar tissue, which often limits the motion of joints, especially after burns, infections, or extensive injuries, and draws them into extreme positions

Treatment. Prophylactically, we should plan our incisions to conform with the creases and folds in the skin If we excise a keloid scar, that is, one at a right angle to the line of the skin wrinkles, a new keloid will form If the keloid is short enough so that it may be removed by an elliptical incision in the line of the wrinkles, a new keloid will not form We can excise a short keloid and close the incision by a

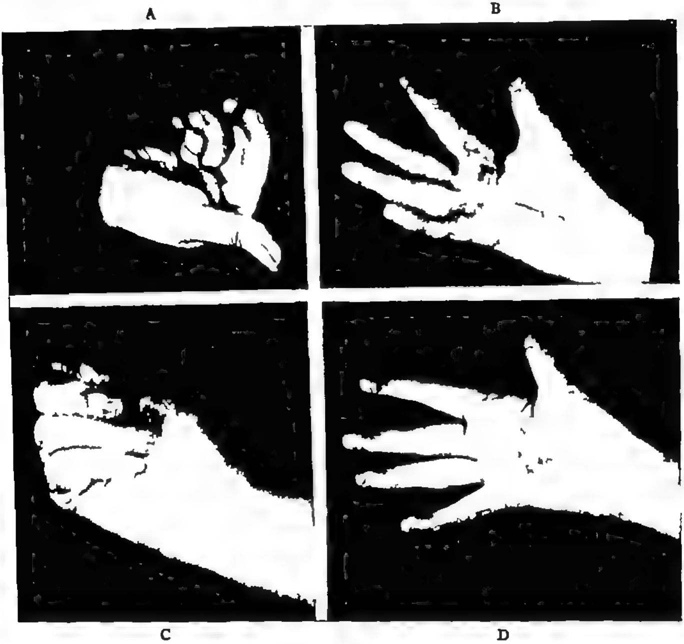


FIG. 104 Case L. M Ten months previously hand was burned by being caught in a mangle. The distal part of the palm including the palmar fascia, sloughed and the area had been later covered by a poor pedicle skin graft. The hand as seen in (A) and (B) shows flexion and extension much limited. There is a stellate contracting keloid in the palm drawing together the thumb and fingers. The grafted skin is dome-like and does not stand work. The flexor tendons are held by adhesions in the palm and fingers.

Operation All of the scar tissue was dissected out of the palm, including that which matted together the deeper structures. The tendons were stripped well into the fingers and mobilized A tubular pedicle which had been prepared and taken from the abdomen was used to furnish good skin for the palm. A splint held the fingers in extension. The result obtained in flexion and extension of the fingers and in new skin in the palm is shown in (C) and (D) taken six months later (Courtesy Surg., Gynec., and Obstet., 39.261 1924)

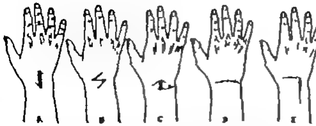


Fig. 105 *Methods of improving a disfiguring keloid scar that has resulted from an incision being at right angle to the wrinkles.*

(A) Scar commonly seen from removal of ganglion Two diagonal incisions are made and the scar excised.

(B) Closure is made in zigzag the cross scar of which will be inconspicuous but the two diagonal members will show

(C and D) The scar can be removed with an ellipse if not too long leaving an inconspicuous transverse scar

(E) Showing how in an L scar the arm parallel to the wrinkles will be narrow but the arm crossing them will thicken to a keloid

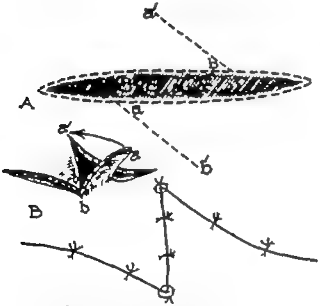


Fig. 106 The ever-useful zigzag plastic. By it the transverse slack is utilized to relieve the line of tension. a is transposed to a and b to b Intermittent tension causes keloid, but after the zigzag plastic the tension is spent, merely opening out the angles of the scar

zigzag plastic with some improvement. The cross-line of the zigzag will not form a new keloid, but the two short oblique ones will. Immobilization for three weeks postoperatively aids in lessening development of new keloid.

Roentgen exposures will make a keloid disappear only if used in dosage that will influence the surrounding and deeper tissues. Radium, which can be more locally applied is preferable for small keloids. Irradiation can be used prophylactically following excision of keloid so that it will act in lessening the new growth of keloid As a whole however, radiation is unsatisfactory, though in some cases it has helped

FLEXION CONTRACTURES

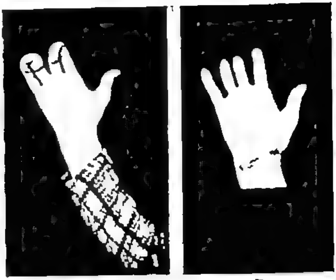
Contractures of the hand usually result from infections or burns The infection may be primary or may follow traumatic tissue destruction Contractures from burns involve essentially the skin and may include some deeper tissues They were caused from without inward, while those from infections were primarily of the deeper tissues and secondarily involved the skin. The skin cicatrix was from sloughing following injury and infection, or because the incisions for drainage were placed so that they crossed flexion creases.

Effect of Infections

Stage of Destruction. The longer the *infection lasts the greater is the growth of* granulation tissue and consequently the greater eventual cicatricial contracture. Therefore, we should terminate our infections quickly by accurate diagnosis, by choosing incisions which will drain each fascial space or tendon sheath adequately and still never cross flexion creases at a right angle, as this leads to flexion contracture. During the healing position of function should be maintained by splints and intermittent exercises should be started early

The greatest damage from infections occurs in enclosed tunnels, such as in the wrist or fingers When tissue in such enclosures swells blood is excluded and ischemia occurs resulting in necrosis and sloughing and followed by contracture.

FIG. 107 Case L. H Flexion contracture from infection and median longitudinal incision. To reconstruct the finger new good skin by the tubular pedicle method is necessary



A B

FIG 108 Case D K.
(A and B) Replacement of pulp of each finger by tubular pedicle method.

Such spaces should, for decompression and drainage, be opened laterally

When the palmar space is infected the intrinsic muscles of the hand become paralyzed by being bathed in pus, thus upsetting muscle balance and resulting in claw hand. As the infection travels up along the ulnar nerve in the forearm, these same muscles are further paralyzed resulting in increased deformity Subsequently, the cicatricial formation encases these structures in the positions they assume, establishing the flexion contracture.

Stage of Healing and Contraction Inflamed and granulation tissue throughout the hand and forearm gradually contracts, binding all of the tissues together in a dense octopus-like contracting scar Just as the area of skin involved may shrink to two-thirds or one-half its size, so does the deeper tissue including deep fascia and the deep connective tissue which surrounds all structures. This solidifies, shrinks, and draws to itself from all directions. Infected muscles shorten as they contract with fibrosis and so do the parts of joint capsules that were involved in the infection. Tendons are reduced to contracting scars firmly attached to the surrounding tissue. Tendon sheaths greatly proliferate and attach themselves to their surroundings and contract, thus, all of the tissue may share in drawing the joints into flexion This in the hand applies particularly to the wrist, the cleft between the first two metacarpals, and the distal two joints of the digits.

Secondary Effects of Contractures Infection follows blood and lymph vessels and nerves, especially the ulnar nerve. Granulation tissue forms around these structures and in the final contraction strangles them, impairing their function Their lessened nerve supply results in atrophy of all of the tissues, stiffening of the joints, and adherence of tendons The lessened blood and lymph supply results in impoverishment of tissues, edema, and cyanosis The whole hand becomes firm, atrophic, cyanotic, and poorly nourished In this so-called congealed hand the joints become stiffened and the tendons adherent, and there is pain, paresthesia, diminished sensation, and distress when cold

In skin, the irritation of the scar from intermittent tension results in keloid formation. Thus, where a scar crosses a flexion crease every effort of extension increases the keloid formation and this in turn the contracture. The same is true of the deep cicatrix of connective tissue, in some persons more than in others.

Secondary to contractures muscle balance is upset, while one group of muscles is over stretched and weakened, the opposing group is allowed to contract and become fixedly so

In flexion contractures many tissues are involved. Some are primarily affected and others, including all from the skin to the capsules of the joints, follow secondarily, due to the flexed position If, on stretching, the skin whitens, the skin is the primary cause of the contracture, the deep structures being contracted secondarily If the skin does not whiten, the deep tissue is primary and the skin secondary

Rôle of Tendons in Contractures

A sloughing tendon is eventually replaced by a contracting cicatrix, which attaches to the surrounding tissue and

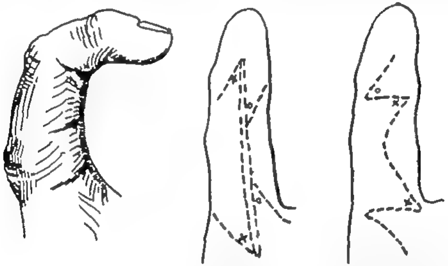


Fig. 109A. Showing method of relieving the linear flexion contracture of a finger which results from the "pernicious median longitudinal incision." The transpositions of the flaps in the zigzag plastic are indicated by *X* and *O* (Courtesy Jour Bone and Joint Surg., 14 27 No 1 1932)

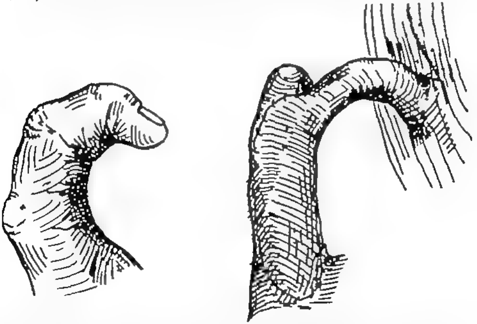


Fig. 109B Method of relieving a severe degree of flexion contracture of any joint by substituting for the cicatrix good pliable skin by a tubular pedicled skin graft. The borders of the skin graft should not cross flexion creases at right angles or contracting keloids will develop. (Courtesy Jour Bone and Joint Surg., 14 27 No 1 1932)

draws the joints into flexion. The tendon sheath proliferates greatly and similarly attaches itself and contracts. Such a firm cord cannot be drawn out by continuous traction. Physiotherapy is useless. The damage found at operation is always worse than expected. When a tendon is severed by sloughing, its end always becomes fixed. It is only when a tendon is severed in a self to the surrounding tissue, and then contract.

General Principles of Treatment

For contractures and cicatrices conservative methods of treatment alone (such as long-continued, constant, mild traction) will draw stiff joints into position of function, will elongate soft cicatrices and con-

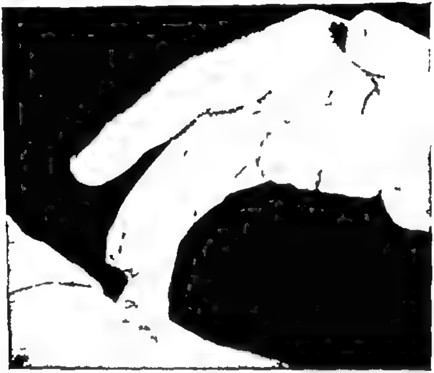


Fig. 110. Resurfacing of finger for flexion contracture by tube pedicle in one stage. The scar should follow the midlateral line of the finger to avoid thickening from push and pull. (Courtesy of Darrel T Shaw Capt., M.C., Baker General Hospital.)

sheath and without infection, that it becomes rounded over without any attachments. When severed in paratenon formation or in the presence of infection, the tendon end always proliferates and attaches to the surrounding tissue, contracting and often resulting in a flexion contracture. The distal end of a flexor tendon left in a finger will often attach, contract, and draw the finger into contracture. That part of a flexor tendon distal to an attachment always becomes adherent throughout the length of the finger and limits extension of the finger. Similarly, any free tendon end left in the tissues predisposes to contracture from its tendency to reach out, attach it

tracting muscles, but will not draw out adherent cicatricial tendons—nor will physiotherapy, even if used by the year. The traction method is advisable for mild cases and for preliminary use in the more severe ones. It will place stiff joints in position of function so that the patient can use the hand, and thus will improve it by exercise.

In contemplating repair of a contracted hand we should first picture in our imagination the normal hand with a clear conception of its anatomy and physiology. Only then can we perceive and calculate the defects in skin and deeper structures, nerve, lymph and blood supply, muscle balance, and nutrition. Our conception of the hand

should include the range of motion of each joint and of the hand and digits as a whole, including function from a practical stand point. The creases and folds in the skin are each for the definite purpose of accom modating movements, so these may be executed throughout their full range without resistance of binding or friction. A conception of some of the details of the normal hand has been given in Chapter 2 With these in mind we can better realize the de fects and problems involved in the hand to be repaired

Our first procedure is to furnish new skin and to correct the contracture. The struc tures inside the hand are liberated by substituting for the tight, binding cicatrix good, pliable skin by the use of the pedicled skin graft. For contractures from burns, thick free grafts are generally used. This results in marked improvement in the general nu trition of the hand At this procedure suffi cient of the deep cicatricial structures is excised or severed to overcome the contrac ture of the joints. The hand is placed on a previously prepared metal splint in the posi tion opposite to the contracture and a skin graft is applied Tendon grafting or repair

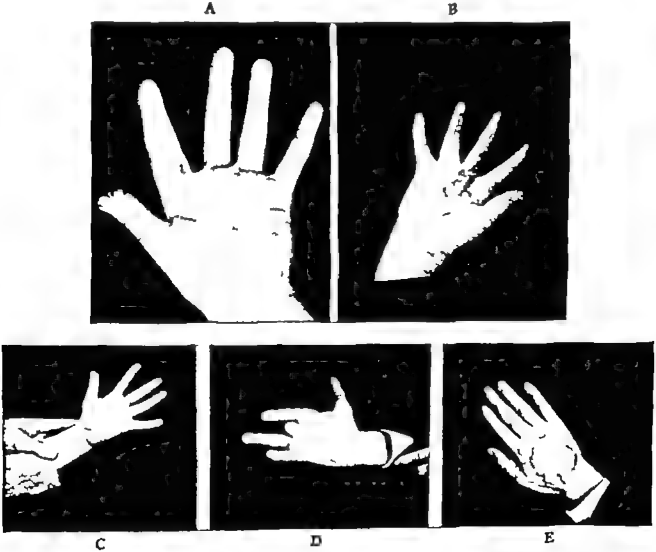


FIG. 111 Examples of using the tubular pedicle graft to replace cicatricial contracture in the hand.

(A and B) Median longitudinal scar replaced by good skin.

(C) Thumb had been drawn in to hand. Good skin substituted for cicatrix.

(D) A cloth wet with turpentine and a match led to amputation of a finger and contracture of thumb and fingers into palm. Replaced by tube pedicle skin.

(E) Chronic ulceration from excessive cicatrix replaced by good skin.

A B C

FIG. 112 Case M. C.
(A) Finger held in extension from extensive cicatrix on dorsum of two fingers and hand with loss of one finger from crush and laceration between rollers.
A tubular pedicle from abdomen was substituted for the cicatrix on the dorsum of the hand, then waltzed (B) to the fingers and the clefts were deepened (C) After six months he could make a fist.

is omitted at this skin grafting stage for fear of infection.

Frequently, the contracted joints cannot be extended at once because the nerves have shortened. By gradual continuous extension, however, over a period of a few weeks they will readily elongate. The second operation is done a few months later when the new skin will have sufficient vitality At this time the deep structures are repaired. The tendons, nerves and vessels are not only dissected out from the scar tissue, but the extensive deep connective tissue cicatrix which reaches out like an octopus with all its tentacles and binds and strangles is excised until only good tissue is left, because cicatrix in healing makes more cicatrix. By freeing the nerves from encircling scar and liberating all the deeper tissues, great improvement in the nutrition and trophic effect in the hand results. The state of nutrition of a limb is the most important factor influencing the return of function as regards tendons, joints, and nerves.

If in contractures the joint capsule is still holding, it should be severed or excised in its shortened part. Usually, if merely severed, the edges will rejoin They may also do this if excised, unless prevented by splinting. If the joints of the digits are injured or destroyed improvement can be made by a capsulotomy, arthrodesis, or arthroplasty, to put them in position of function and to give them more motion Similarly, the wrist may be placed in moderate dorsiflexion and, if painful or showing too little movement, either ankylosed or given motion by arthroplasty The treatment of joints and contractures may be found in Chapter 7, Joints.

Tendons in contractures, if reduced to scar tissue, should be excised and replaced by free tendon grafts. Tendons that have been severed for several months must be dealt with likewise, because the proximal ends will have retracted and the distal portion will have degenerated from disuse and will be adherent. Consideration of tendons in contractures may be found in Chapter 9, Tendons.

Plastic Repair of Skin in Flexion Contractures

In flexion contracture the area of skin over the contracture is too small There is a defect in the amount of skin present the size of which can be estimated only by picturing in the imagination the hand in the extreme opposite position to the contracture, the contracture entirely excised and the surrounding skin liberated so it is free to retract to its normal tension The skin defect is then seen to be greatly in excess of what one would estimate. The

minimum defect, for instance, in a strongly flexed wrist is three inches in diameter

A

B

C

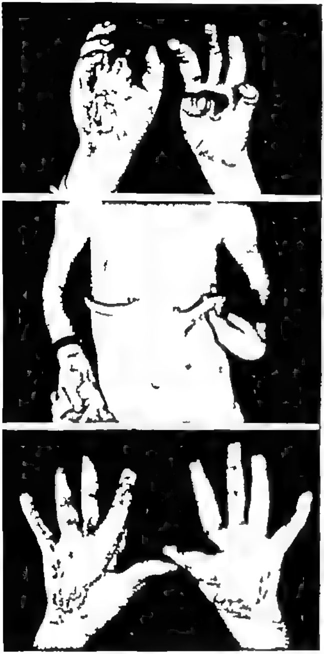
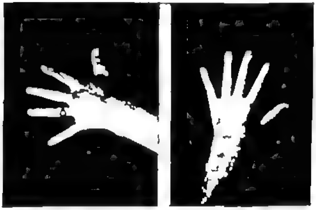


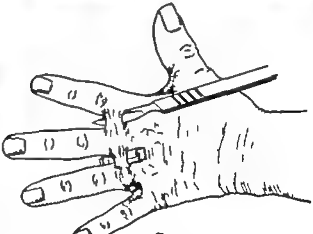
FIG. 113 E. M., aged seven. At the age of 14 months his chair fell forward and both hands rested on a hot stove, resulting in the deformity seen in (A) The digits are at their limit of extension.

Operation Two tubular pedicles were prepared as in (B) The scars on the moderately contracted fingers were relieved of their tension by cutting a series of V's along them and suturing them in Y's. The large keloid scars were excised and the areas covered with good skin from the pedicles. The hands were held in extension by metal splints. The result immediately after the completion of the operations is shown in (C) (Surg., Gynec., and Obst., 39 2 1924)

Contractures are greatest along directions of push and pull, as *they are caused by this* irritation The length and breadth of the defect are ascertained by comparing measurements with the other hand, with all of the joints placed in the position opposite to that caused by the contracture. Comparative distances between various similar two points are taken longitudinally down the wrist, palm or fingers, and transversely in various lines across the palm with the five digits fully spread or across the dorsum with all fully flexed In estimating the size of our pedicle, one third more is added to allow for the tightness of the skin about the

A B





C

FIG. 114 Case C. H

(A) Webs from an electric flash burn.

(B) Corrected by tunnel grafting.

(C) A scalpel is thrust through deeply under the web and through this hole is placed a skin graft wrapped on a metal strip In ten days the web is slit through. The depth is found epithelized and the side wounds soon heal.

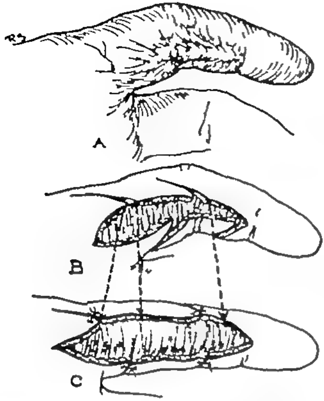


FIG. 115 Correction of flexion contracture in a finger After excision of cicatrix the borders of the wound can be lengthened by oblique cuts, allowing each point of skin to slide proximally

Note These scars being arterolateral instead of true lateral will make contractures.

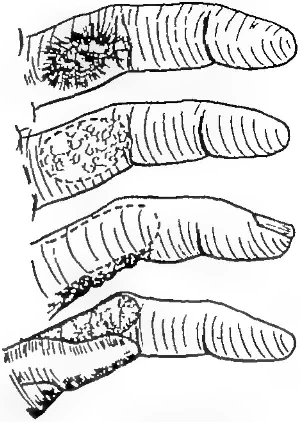


FIG. 116 A volar cicatrix should be excised. A flap of skin taken from the side of the finger may be used to cover the volar aspect. The area denuded is covered by skin graft.

contracture. Before a hand can be placed in the opposite deformity, the deep portion of the flexion contracture must be relieved whether it is fascia, tendon or joint capsule Only in slight contractures or small scars of the hand can sufficient good skin to cover the defect be obtained from the vicinity by sliding or swinging skin flaps Usually we must resort to the free or pedicled graft method.

Plastic Procedures

Small scars may be excised. The surrounding skin should then be widely undermined, so as to detach it and make it possible to draw the skin margins together by suture. The undermining should be in a plane between the superficial and the deep fascia, because the superficial fascia and skin will stretch, but the deep fascia will not. If the scar parallels the creases in the skin simple excision is all that is necessary, but if it crosses them, some maneuver should be done by which the resulting scar will, if possible, parallel the creases. This may be done by excising with a wide ellipse in the right direction by a sliding skin graft, or by a Z plastic. When a scar shows a narrow line of contracture from tension one may swing a flap of good skin across the line of tension, resort to a V to Y plastic, place a tunnel graft across under the line and later cut it through, or employ the most useful method of Z plastic Our problem is to elongate the skin in the line of tension at the sacrifice of the slack skin in a line at a right angle to this By transposing the two pointed flaps in the Z plastic our straight line of pull is converted to a zigzag line, so that the tension expends itself in merely broadening the angles of the scar By drawing the skin together crosswise to the line of tension, like fitting two crowns together, the skin is made greater in length in the line of tension

Z plastics are good for web contractures

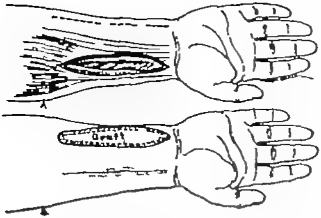


FIG. 117 Method of obtaining skin to close a wound.

After an operation on forearm, adding grafts or removing scars, it may be impossible to close the wound. By making a parallel incision the broad ribbon of skin is sideslid enough to cover The denuded area is skin grafted.

anywhere, especially about elbow and axilla. If skin is insufficient, these may be combined with the addition of a free skin graft in a part that does not move. For a long contracture multiple oblique cuts alternating on each side convert the web into a long zigzag line free from tension. By the Z plastic, which means transposing one flap for another, poor skin at a place of motion may be replaced by good skin, the poor skin being displaced to where it can be removed by multiple excision

Tunnel grafts are made by thrusting a knife across well under a contracture and placing through this tunnel a split skin graft

FIG. 118. To mobilize skin for pedicles, flaps, or other shifting the undermining is done in a fairly bloodless plane between the deep and the superficial fasciae. Only *the former of the two will stretch.*

folded upon itself with its raw surface outward, either about a flat stent or not. In ten days the tunnel is slit through and the wound now lined with skin gapes open in the line of tension. This method is particularly useful in *determining the depth of* an interdigital cleft in the cure of acquired syndactylism.

In opening out a finger that has flexion contracture after the scar is excised from the volar surface, it will be found that the skin is too tight along the sides to allow the finger to straighten One or two diagonal cuts into this border of skin allow the finger to straighten, as the points of skin so produced slide proximalward and can be sutured there The resulting defect is closed by graft. (Fig 115)

A small area from which skin has been excised can be closed by swinging a skin flap from the neighborhood over the defect. The bed from which the skin flap came can then be closed by an immediate split graft. This allows us to cover with good skin areas that must stand the wear clefts, or structures that would be vulnerable to infection or that have just been repaired. This procedure applies to the volar or dorsal surfaces of the fingers the dorsal surface of the hand and the arm A contracture of one finger may be replaced by a skin flap from the side of the adjoining finger, skin grafting the donor site

The palm, being thicker and stiffer, does not lend itself well to the swinging of skin *flaps, because the torsion of the inelastic* base of the flaps cuts off the blood supply In the fingers, the flap is usually swung from the side, but its pedicle must be proximal.

If the flexion contracture of the finger is narrow the Z plastic may relieve it. By the above procedures as much as possible of the surface is covered and the remainder is skin grafted.

Where skin tension is too great to close a wound after the deep structures have been repaired, as in the forearm, one can make an extra incision paralleling the wound and an

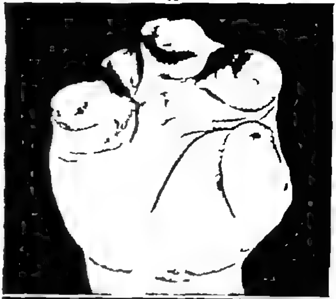
inch or more from it The intervening skin is then undermined and can be slid across so that the wound can be closed without tension The edges of the supplementary incision now gape widely, but can be closed by an immediate split skin graft placed over good subcutaneous tissue and away from where the deeper structures were repaired

To cover a small defect where the circumference is short, as in a wrist, when swinging a flap is not possible, a flap can be advanced longitudinally down the arm either by undermining and stretching or like the progression of a measuring worm, raising and advancing the proximal end first and replacing it by a skin graft.

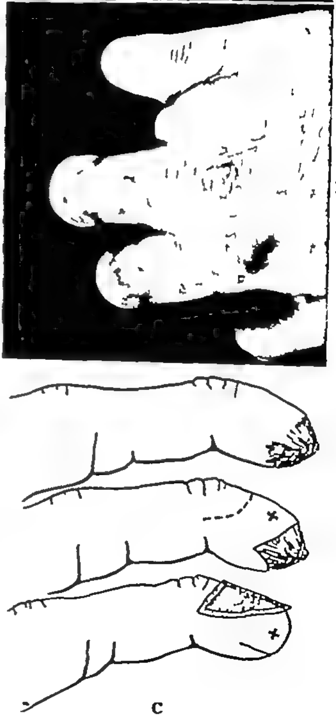
In some the skin of the forearm is freely movable. In others, not. When skin is needed in a longitudinal direction, one can for a week or two preoperatively obtain about 1½ inches of redundancy by applying traction on the skin by stockinet and ace adherent just as we do after a guillotine operation. By these methods much of the dorsum of the hand can be covered by forearm skin, dorsiflexing the wrist at first. The longitudinal scars must, however, be zig zagged at the wrist to allow motion.

In raising skin flaps the undermining should be made just superficial to the deep fascia and liberally enough beyond the base of the flap so that the flap can be turned without tension There should be sufficient subcutaneous tissue to carry blood supply In an extremity the base of the flap should be proximal, whenever possible. A rounded flap is more viable than is a pointed one, and the base should be broad enough for the length of the flap to insure vitality

A



B



C

FIG. 119 When stumps of digits are cicatricial a band of skin taken from across the dorsum can be drawn over to replace the poor end much like drawing a cap down over one's face. The part left denuded is covered by skin graft, which in outline resembles a nail.
(A) Preoperative.
(B) Postoperative. (Courtesy of W H Macomber Lt. Col., M.C., Dibble General Hospital.)
(C) Diagram of operation.

Fig. 120A. When nails and matrices are too deformed as from burns they may be excised and replaced by skin grafts with fairly good cosmetic effect. (Courtesy of L. D Howard, Lt. Col. M.C. Wakeman General Hospital.)

Fig. 120B Fillet of long finger to cover dorsum of hand. Dog ears left for circulation were excised later Note how tip of finger is laid out as a W to handle the pad. (Courtesy of L. D Howard, Lt. Col., M.C., Wakeman General Hospital.)

Fig. 120C. The index finger which, from gunshot wound, was beyond repair was discarded and the cicatrix of cleft and dorsum was replaced by volar skin by filleting the finger Later use of the long finger was restored by bone and tendon graft. (Courtesy of L. D Howard, Lt. Col., M.C., Wakeman General Hospital.)

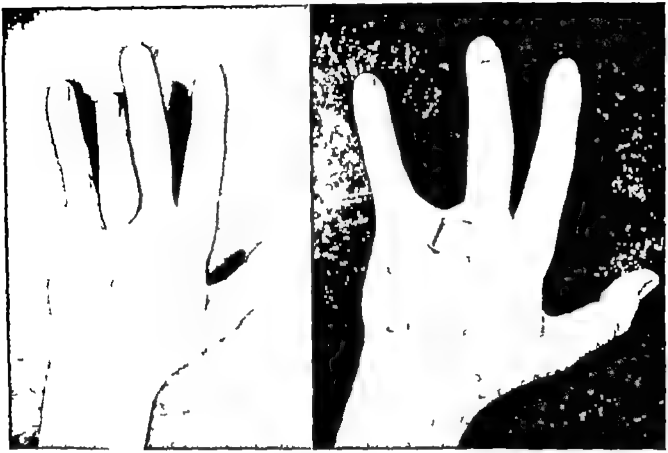
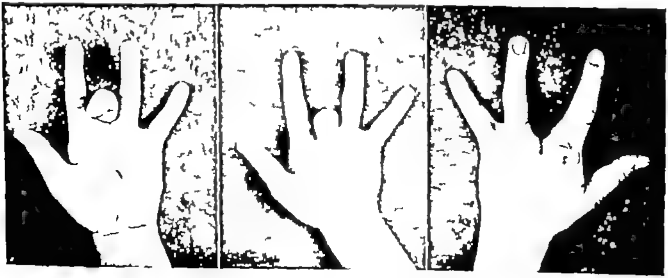
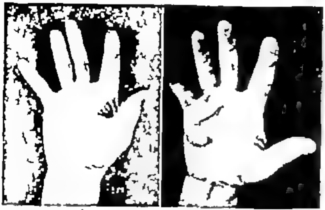


FIG. 121A. Use of fillet of finger skin for dorsal defect. (Courtesy of L. D Howard Lt. Col., M.C., Wakeman General Hospital.)

FIG. 121B Method of using volar skin of a finger to cover both volar and dorsal defects.
(*Left*) A cicatrix is in the palm and over the dorsum of the proximal finger joint.
(*Center*) After boning the finger a patch of distal palmar skin together with the volar skin of the finger was displaced proximalward to replace the cicatrix.
(*Right*) At a second operation the volar skin of the finger was laid across the cleft onto the dorsum. (Courtesy of L. D Howard, Lt. Col. M.C., Wakeman General Hospital.)





A B

FIG. 122 (A) Contractures from burn in palm. (B) Correction by simply excising undermining and applying full thickness skin grafts to the resulting defects. (Courtesy of L. D Howard, Lt. Col., M C., Wakeman General Hospital.)

FIG. 123 Thumb cleft spreader devised by Wm. Littler The larger leather loop is drawn towards its end of the wire bow by elastic bands. (Courtesy of Wm. Littler)

This judgment can be gained only by experience. The inclusion in the flap of a large artery and vein insures a better blood supply In applying dressings care should be taken not to place undue pressure over the base of the flap

In plastic work certain principles are essential Hematoma should be avoided by hemostasis, brief tube drainage, and gentle, prolonged pressure by voluminous, well fitting waste or fluff wound with an elastic bandage. For accurate healing, immobilization is necessary, as is avoidance of any raw area. Overstretching of skin results in necrosis. Skin flaps should be ample in size and with good circulation. Skin should be undermined widely enough to prevent tension. In plastic work we should be liberal and radical as tension is fatal

Deformities of Finger Ends. Tender cicatricial finger ends are unfit for work. A small abdominal skin flap in one stage will place good skin there, though, being of abdominal skin, stereognosis will be poor The volar skin of a toe as a free or pedicle graft furnishes better stereognosis because of rugae and touch corpuscles. Even a small thick piece of toe pulp may be grafted as we graft a portion of an ear to fill a defect in the nose. In loss of the distal part of the pulp the nail and distal phalanx may be shortened and the volar skin sutured to the nail

Where possible a cicatrix in a place which should be a tactile area may be replaced by normal innervated skin by transposing from the side of a finger the side then being skin grafted. A terminal scar on a finger stump may be replaced by dorsal skin from the stump by making a transverse incision across the dorsum. A ribbon of this skin attached at each end is slipped over the end of the stump to replace the scar, a skin graft being placed on the dorsum, which in outline resembles a nail

Filling Defects Lost contour may be restored to hollows as in the forearm in several ways. Subcutaneous fat may be partially cut loose and rolled out under the skin to fill the defect, or the hollow may be filled with a pedicle skin flap If, however, skin is present, a pedicle skin flap may fill the hollow and then the skin of the pedicle may be cut away Another method is to bury a derma graft with one-half inch of fat taken from the inguinal region, preserving Scarpa s fascia to keep the under surface of the fat intact. First a skin graft is taken to get the derma and fat beneath, and then it is laid back in place. A free graft of fat may be absorbed, but the fat of a pedicle graft will not be. Derma grafts shrink about a fourth.

Utilizing Finger Skin To replace a scar on another finger, the dorsum or palm

of the hand, or both, the skin of a useless finger may be used The finger is slit along the dorsal or volar aspects, filleted, preserving its nerve and blood supply, and laid over to fill the denudation To cover both surfaces, the finger may be split This argues for not discarding fingers at the time of an accident.

If desired to place the skin of a finger remote from the base of the finger, as across a thumb cleft, the skin may be entirely detached or circumscribed with the exception of the two volar digital nerves and vessels which are used as the pedicle from the palm In one instance we succeeded in this when only one of the volar digital arteries was present.

Flexion Contracture of Thumb Cleft This contracture ranges from mild to extreme, and often is of fibrous contracture of all the muscles and tissues between the first two metacarpals including the carpometacarpal joint capsules. Ischemic contracture is the worst.

The zigzag plastic procedure will suffice for mild contractures from scar or burn of web Often a flap of skin from the dorsum of the hand may be swung well across the depth of the cleft, and the denuded part of the dorsum skin grafted A tunnel graft may be used to break a dorsal web or the cleft may be widely opened and a large diamond-shaped free skin graft used to close it. Whenever relieving webs by this method, whether in thumb clefts or between fingers, the points of the diamond should be prolonged far proximal on each side to avoid shrinking to form another web A free graft in a thumb cleft wears so poorly that pedicle graft is preferable.

A pedicle graft here should also, be a long diamond reaching to the angle between the first two metacarpals both in front and in back so as to be free from push and pull on its borders. This is best done by an expansion on a tube, but, also, by a direct abdominal flap, splinting the cleft wide open The skin of the opposite arm has been used, but the scar here is objectionable

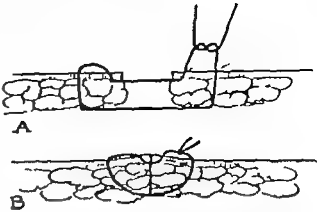


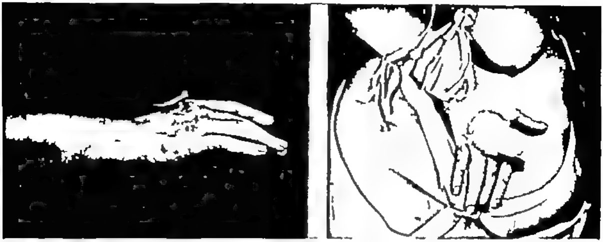
FIG. 124 Far and near retention suture placed in palm to prevent the tough skin edge from rolling in.

The contracture from deep scar will at once recur, unless the first two metacarpals are held apart. This may be done temporarily by inserting two crossed Kirschner wires through the first two metacarpals. The position may be made permanent by a bone graft spreader fitted into slots in the two metacarpals, or between them as a triangular bone block wedge in the position of moderate opposition

Suturing Skin. Any of the various suture materials can be used, but since using stainless steel wire and noting the absence of reaction from it and the perfect healing of the wounds, I have adopted it almost to the exclusion of the other materials.

Needles should be slender and with cutting edges Curved ones are used in the palm and in awkward places, but straight ones are used wherever possible as they are time-saving We use a special needle which is most satisfactory It is spear pointed, .020 inch in width and 2½ inches in length, and is flexible enough to bend somewhat when occasion demands The same needle is our choice in sewing tendons It is obtainable from Reid Bros., 316 Mission St., San Francisco, California.

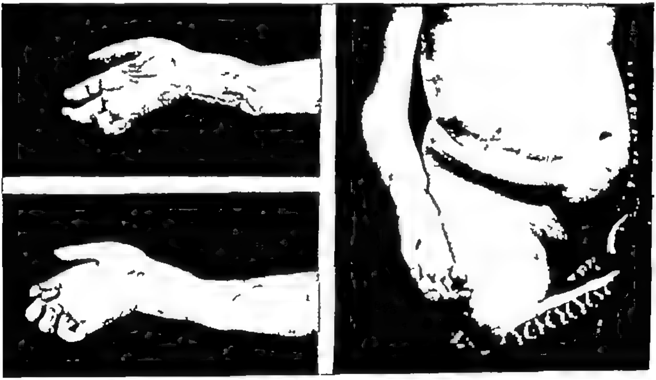
In the palm the skin is rigid and the edges have a tendency to curl in, therefore interrupted end-on mattress sutures are first placed, penetrating straight through each skin border at a right angle one-quarter inch from the wound and returning, catching the edge of the wound *itself* This is followed by a continuous simple over-and-



A B

FIG. 125 Case H. G
(A) From a wringer the tendons and skin were evulsed from the dorsum of the hand.
(B) Cicatrix was excised replacing it by tubular pedicle graft preparatory to placing new tendons.

A B



C

FIG. 126 Case T L. Cicatrix from shotgun wound followed by infection.
Cicatrix was excised as a preliminary operation and replaced with good skin by the tubular pedicle method.
(A) Cicatrix.
(B) Pedicle ready
(C) Cicatrix replaced by pedicled skin.

over stitch for exact coaptation. This mattress method is useful elsewhere in the hand and forearm wherever retention sutures are used. With it we often catch the deeper structures also, so as to obliterate dead space and prevent slithering of the layers of the wound Stainless steel wire Nos. 34 and 35 is used for retention sutures and Nos. 36 and 38 for the finishing apposition stitch. The latter should enter the

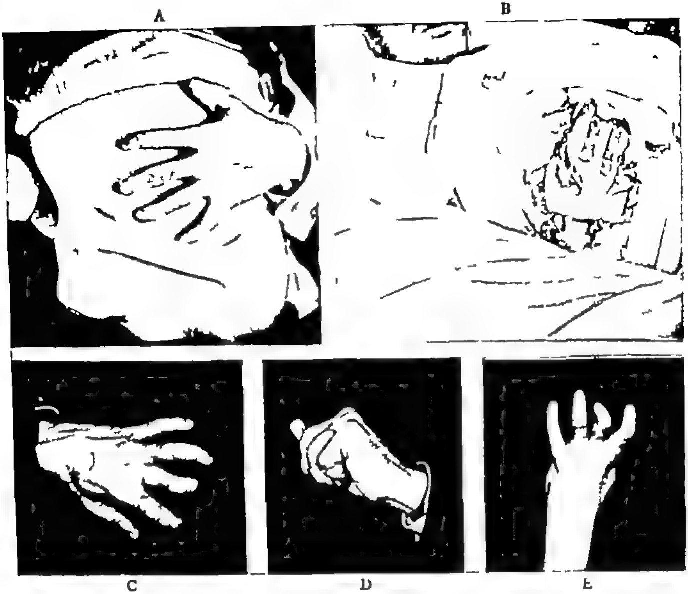


FIG. 127 A surgeon removed a foreign body from a child's hand under the fluoroscope. The hand of each was severely burned. Damaged skin must be excised and replaced by good skin.
(A) X ray burns on dorsum of fingers and pedicle ready to apply
(B) Pedicle on dorsum of fingers. Bolsters hold it between fingers
(C and D) New pedicled skin in place. Returned to practice.
(E) Hand of child after receiving new pedicled skin.

skin two or three millimeters from its border, depending on the skin thickness, and traverse on through the skin, diverging from the incision so as to encircle a sufficient mass of subcutaneous tissue to cause the skin edges to rise up slightly. The stitch up through the opposite skin edge should, of course, embrace the same amount of subcutaneous tissue and emerge the exact same distance from the skin edge as on the opposite side. Sufficient subcutaneous tissue in the grasp of the stitch makes a thicker wall between the inside repaired structures and the outside, and by this broad attachment prevents scars from spreading. Stitches placed too far from the skin edge allow the edge to infold. The tissues of the hand have so much movement that stitches should not be removed until the ninth day, or incisions will break open. To protect the suture line from parting or stretching, the skin tension may be relieved by a butterfly of adhesive plaster crossing the wound, or by strips of gauze painted to the skin with collodion. Whenever plastic maneuvers have been done it is well to splint the hand until the skin has firmly healed, lest movement cause necrosis of such parts of low

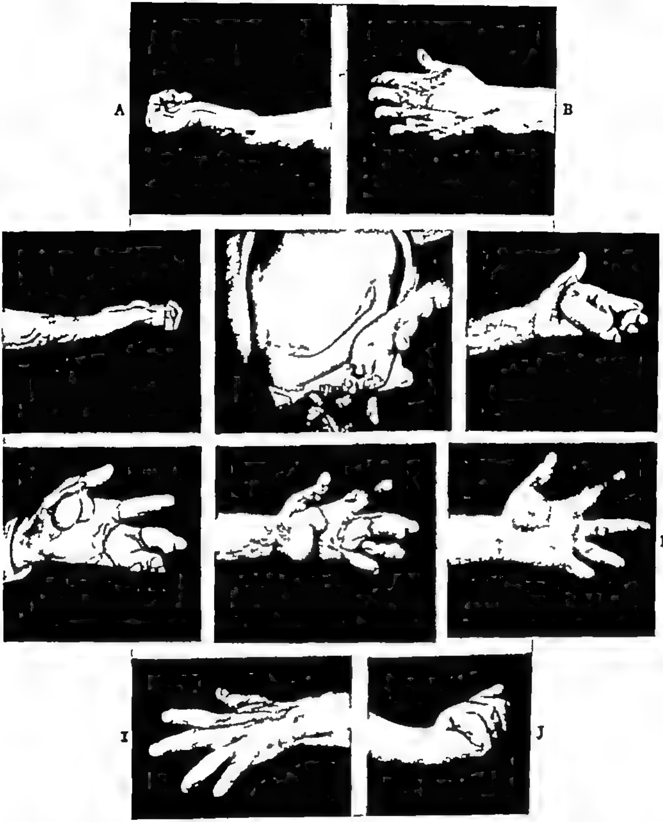


Fig. 128 Case M. J R.

(A, B, and C) From a gasoline burn the hand was reduced to a useless club, with flexion contrac ture of fingers, webs, thumb bound to hand, and much cicatrix.

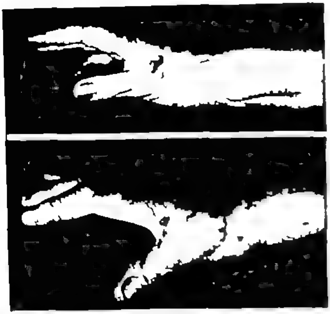
(D *top center*) Pedicle has been prepared and after excising volar aspects of fingers and extend ing them they were covered with Thiersch grafts. The webs were relieved by tunnel grafts.

(E) The volar skin was split along each digit, laid back utured together like a mitten, and the whole volar surface of fingers was covered by the pe severing pedicle from abdomen the end was placed in cleft of thumb.

(F) and (G, *lower center*) tating the digits.

(H, I and J) A year and the accident he hand with good nutrition, sensation and motion restored.

A



B

Fig. 129 (A) Flexion contracture from cauterization of epithelioma nine years previously

(B) Replacement by tubular pedicle graft.

Note The scar along the thumb web is subject to push and pull. Instead a point of the graft should have been prolonged across the cleft.

A B

Fig. 130 Case W D Substitution of good pedicle skin from abdomen for cicatrix *on dorsum of four digits following a* mangle burn exposing the phalanges From abdomen the tube was placed on the index and long fingers, then on the ring finger and finally waltzed to the thumb

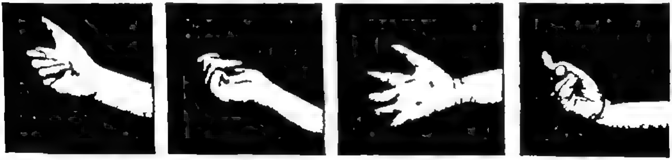
(A) Tubular pedicle swung from ring finger to thumb

(B) Four digits covered with pedicled skin.

vitality as the points of skin or the ends of skin flaps

Skin Grafts

Wherever the area of cicatrix is extensive we should excise all scar tissue and supplement in its place good skin by means of some method of skin grafting When the cicatrix is unusually extensive, running well up the arm, it may not be practical to excise all and replace with good skin In such a case, we should determine the locations *of the main lines of tension These lines* should be broken by excision and cross-cuts. The skin should be allowed to gape widely by freeing its margins, and the denuded areas should be grafted Occasionally, in broad cicatricial areas the tension can be relieved by cross-cuts across the whole area,



A B C D

Fig. 131 Case M. F

(A and B) The right hand was drawn into a hot mangle. After the slough, including all flexor tendons, the contracture drew the fingers into the palm causing total disability except for pinch between thumb and side of index finger

First, the cicatrices were severed and excised, allowing partial extension of the fingers closing with skin graft. Later each finger was cut down the center laying back the volar skin flaps and joining them into a mitten On the denuded volar surface a tubular pedicle was laid interdigitating it later

(C and D) Condition on completion. Sensation returned. New tendons were not necessary as joints were ankylosed. She learned to draw and became an artist.

dividing it into segments. Split grafts are then laid over the defects so produced. Occasionally the tunnel method may be used, placing the split skin graft over a wide flat stent of wax or metal placed through the tunnel, or even imbedded under the skin without a through-and through tunnel and later slit widely open.

The choice of what type of graft to use depends on the bed to receive the graft, on the use to which the part must be put, and on the time, operations, and expense incurred Skin furnished by the pedicle method is by far the best and is necessary in contractures resulting from infection, because in these deeper tissues are involved

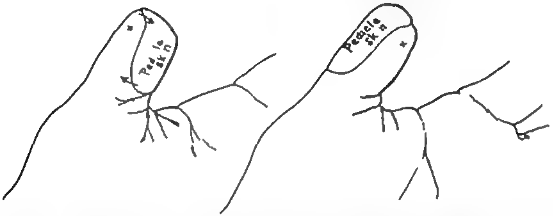


FIG 132 Half of the function of a thumb is tactile. As a pedicle graft never yields as good sensation as does normal digit skin, whenever possible the tactile surface of a thumb or index finger should be of normal special corpuscle-bearing skin. By a flip-flop or transposition normal sensation may be furnished to the special tactile area of the opposing digit.

FIG. 133 Free graft of skin on dorsum of hand in which the error was made of allowing its border to coincide with the web of the thumb. Due to the irritation from push-and-pull flexion contracture developed. The graft should have been prolonged as a long point well around the web on the volar surface.

FIG. 134A (*Left*) Contraction between thumb and hand.
(*Center*) Replaced by expansion on end of tube pedicle crossing cleft liberally to avoid contracture
(*Right*) Abdominal defect closed by skin graft (Courtesy of L D Howard Lt. Col., M C Wakeman General Hospital.)

and the bed to receive the skin graft is cicatricial or may be of bone, tendon, or joint capsule. Cicatrices from most burns have a good vascular bed, as the damage was inflicted from without, so these are well adapted to receive free, full, or thick skin grafts.

A pedicle graft with its subcutaneous tissue will bring vascularity to the deeper cicatricial tissues, so in withered limbs with poor nutrition the pedicled graft is preferable to the free graft. In areas subjected to much movement where there are flexion creases pedicle grafts are especially indicated, in contrast to split or Thiersch grafts, though full thickness grafts here are often quite satisfactory Where there is much wear and hard usage, as over the volar aspect of the digits and palm, pedicle grafts wear better than do free grafts. The ordeal of using the pedicle graft method requires a series of operations and hospitalization of many weeks, consequently there is more time and expense involved than with the free graft, which is done in one operation.

The pinch graft should be mentioned only to condemn it, for it yields unsightly, irregular poor skin and the donor areas are not only extensive and hideous but are spoiled for yielding subsequent crops of skin It is easier and better to obtain the small pieces by cutting up skin which has been cut in the usual manner for graft

The Plastic Operator Should Have Due Regard for the Deep Structures Of the whole hand problem, the skin is only a part If, when the pedicle skin is placed careful notes as to the condition of the deeper structures are not made, the later deep repair will be handicapped All dissections of the hand should be done under the ischemia of a pneumatic tourniquet This should spare the deep structures from injury to nerves, tendons, blood vessels pulleys and joint capsules Severance of the motor thenar nerve destroys opposition and of a volar digital nerve, sensation Incisions that parallel tendons cause adhesions to the tendons their full length Skin replacement should be planned so that, when later the deep structures are repaired, a flap may be turned back rather than placing the scar directly over the repair These, and many other points, show that it is best, even in organized hospitals, for the man who repairs the hand to do all of the work of the hand including the plastic procedures

The Hand Is a Tactile Organ. In the hand sensation is equal in value to motion The hand is a sense organ specialized for stereognosis This is especially true of the area supplied by the median nerve The pulps of the thumb and first three fingers are the eyes of the hand. Their rugae fur

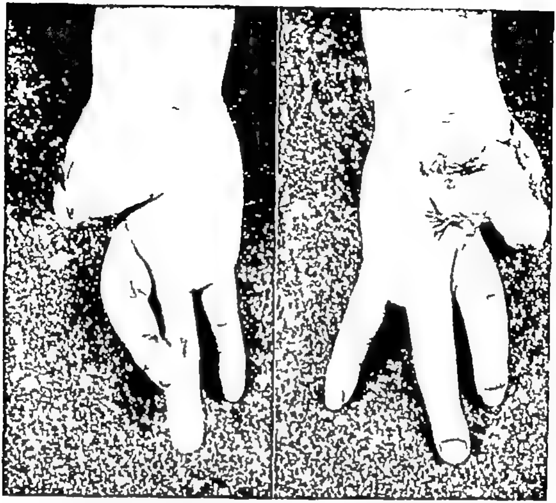


FIG 134B (*Top*) Defect in hand from gunshot wound. (*Bottom*) Long finger was filleted and placed over thumb stump to provide normal tactile surface. Delayed pattern expansion on tube pedicle replaced cicatrix in cleft and dorsum. (Courtesy of L. D Howard, Lt. Col. M C., Wakeman General Hospital.)

nish separate points of contact for crisper images and the pulps are rich in special touch corpuscles. When we construct a new thumb or finger using pedicle skin from the abdomen, or place a patch of this on the tactile surface of a digit, sensation to distinguish touch or pain will return, but not at all like the quality in normal finger skin that makes for stereognosis. Therefore whenever possible, it is well in these strategic areas to by transposing normal skin from the vicinity for pedicle skin furnish this quality of sensation The nerve attachments should wherever possible accompany the skin flap When a finger is to be discarded its volar skin may be utilized, transferring it as a pedicle with blood vessels and nerves intact to the digit which is in need of tactile covering In reconstructing a thumb it is of great advantage to do it by transferring another digit with its blood vessels and nerves attached to the

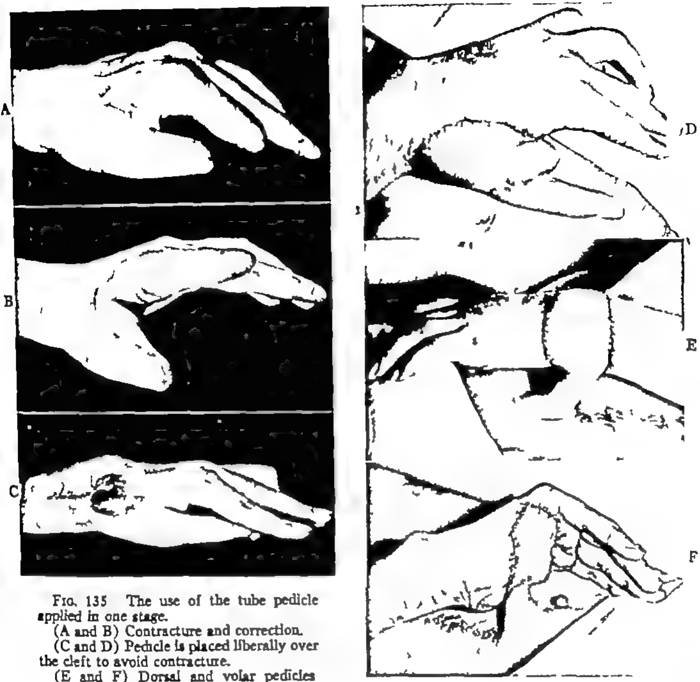
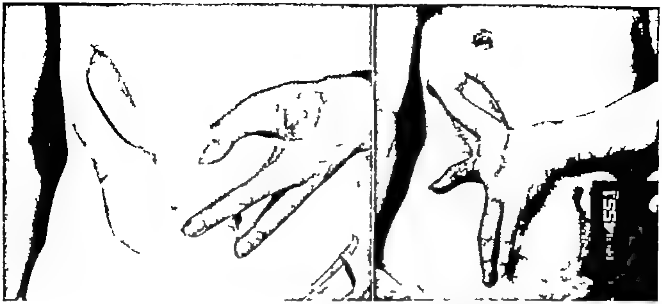


Fig. 135 The use of the tube pedicle applied in one stage.
(A and B) Contracture and correction.
(C and D) Pedicle is placed liberally over the cleft to avoid contracture.
(E and F) Dorsal and volar pedicles (Courtesy of Darrel T Shaw Capt. M C. Baker General Hospital.)

new thumb so that it will have normal sensation

Nerve supply eventually comes into grafted skin, so that light touch and pin prick can be felt, though sometimes not with *normal acuity* *In hands there are* specialized touch corpuscles for a fine degree of stereognosis The tactile corpuscles of abdominal and other skin are relatively poorly developed, so skin from these areas cannot be expected to yield as good stereognosis as is normally present in the hand, which is a special tactile organ, as may be readily determined by placing an object on the abdomen and then in the hand In pedicled skin return of sensation extends gradually from its proximal to its distal part, but return of sensation in free grafts usually comes in all areas at about the same time, and the thinner the quicker, though in a digit it is more apt to be serially

The Hand Is a Mobile Organ. The *skin of the hand is so specialized that it* covers throughout and without strain irrespective of the many positions this versatile and mobile organ may assume Too frequently the physician applies skin to the

A  B

C 

FIG 136 (A) Flexion contracture from gunshot wound between thumb and remaining two rays of hand. Some filleted skin had been applied. Tube pedicle with pattern expansion was made and the bed was skin grafted.

(B and C) Pedicle applied. (Courtesy of W B Macomber Lt. Col., M.C., Dibble General Hospital.)

hand merely as a surface patch replacing a cicatrix, unmindful of this problem. The borders of the patch, if they coincide with the directions of push and pull are subject to the irritation of push and pull and will form thick, contracting keloid-like scars Before any incision in the hand is made this principle should be considered In cisions should parallel the wrinkles or flexion creases wherever possible and never cross them at or near a right angle. A median longitudinal incision anywhere in the hand is pernicious. This principle, so evident in hands which are mobile, applies to skin throughout the body It applies especially to the borders of a skin graft whether the graft is free or pedicled

On the dorsum of the hand is fine cross-wrinkling to give length of skin from the forearm to the finger nails when we make a fist with the wrist in flexion Special redundancy caps the knuckles for free movement. Our skin plastics must regard these features An example of error is the placing of a pedicle graft on a circular patch on the dorsum of the hand so that the distal border parallels the thumb web and the proximal border forms a line across the back of the hand. The border along each web because of the motion of push and pull, thickens to a keloid contracture and the proximal border contracts so that the thumb cannot oppose and the metacarpal arch cannot curve. There is a transverse stretching of the dorsal skin as well as longitudinal. In fact the whole area of dorsal skin of hand and fingers is one third greater on making a fist

The volar aspect is cleft by deep folds These take up the slack of skin on making a fist. The total volar skin area on making a fist and flexing the wrist is very small compared with when spreading the hand

A B C

FIG. 137 (A) Cicatrix drawing thumb to hand and long finger
(B) Replaced by delayed pattern expansion on tube pedicle.
(C) Allowed free adduction of thumb (Courtesy of L. D Howard Lt. Col., M C., Wakeman General Hospital.)

and dorsiflexing the wrist These folds are transverse in the fingers, thumb, palm and wrist, and in the palm are, also, oblique to accommodate closing and spreading between thumb and the last three fingers If a surgeon bears the importance of these structures in mind, he cannot place an incision or a border of a pedicle or free skin graft directly across either the deep volar folds or the fine dorsal wrinkling He must picture the hand as mobile and so arrange his scars to accommodate motion in any direction

When new skin is supplied to the hand, the amount should be ample to cover when the hand plus wrist are in complete flexion and also in complete extension and dorsiflexion, including any additional slack needed to allow, at the same time, full pronation and supination Transversely the palm should have sufficient skin to accommodate for the full spread, and similarly the dorsum for opposition of the thumb and a fully curved metacarpal arch.

Whenever a scar or the borders of either a pedicle or free graft may cross a flexion crease at a right angle, that is, coincide with the direction of push and pull, a zigzag or curved line should be made A cross slit may be cut and a tongue of skin drawn into it, or the patch may be patterned with indentations and blunt points in accordance Instead of allowing a scar to parallel the web, a long tongue of the graft should be laid across the web To fill a thumb cleft the pedicle graft across it should be long and diamond shaped, the points or angles reaching to the juncture, or hinge, of the first two metacarpals both in front and in

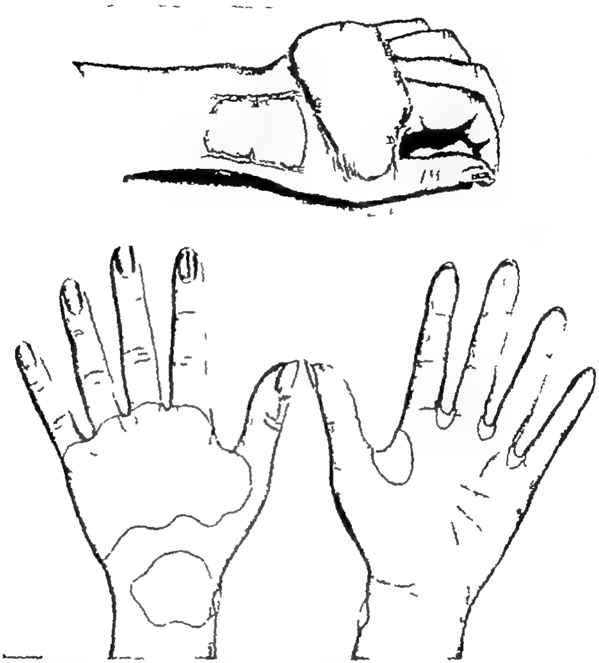
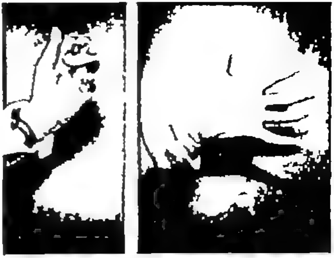


FIG. 138 (*Above*) Poorly made pedicle skin graft with 5 faults namely
(A and B) A longitudinal border of graft in any part of the circumference of the wrist, which is a universal joint, is subject to push and pull and is therefore, irritated into a contracted keloid scar
(C) When this scar contracts the hand will be unable to form a metacarpal arch or place the thumb in opposition.
(D and E) A border of a graft that parallels a web thickens and contracts from the irritation of push and pull.
(F) This graft was made too dome-shaped to give sufficient skin but after all it is the contracting borders that count, as skin surface will spread to accommodate. Excess fat is parasitic. Sufficient blood supply is between the skin and the fat.
(*Below*) Properly made pedicle grafts. They are flat with the surface. A cut is filled with a point in each border (A and B) to form zigzags. Line (C) is converted into a wavy line to allow opposition of the thumb and curving of the metacarpal arches. Every web (D and E) has a tongue of skin laid across it to prevent rewebbing. To summarize, the hand is resurfaced as a movable organ.

back. Longitudinal scars or graft borders about the wrist are bad in any part of its circumference, as the wrist is a universal joint. In fingers the flexion creases extend back only to the midlateral line. Along this line a scar may become invisible, but let the scar be placed more volar or more dorsal to it and it will thicken and contract, because it will be subject to the irritation of push and pull. In applying free grafts to replace scar from burns along the dorsum of a finger one should either zigzag the borders or furnish enough skin to allow the borders to follow the midlateral line of the finger on each side. (Fig. 102.)

PEDICLE SKIN GRAFTS

Pedicle skin grafts furnish good skin and subcutaneous tissue, relax all tissues within the limb thus improving nutrition and bringing blood supply to the part. They will cover over a poor base or any kind of avascular tissue if it is aseptic and will heal, but with considerable scar tissue in a mildly infected field. They may, with the aid of penicillin, be applied as a primary procedure in wounds with denudation, and may be applied to cover any wound from days to weeks after the injury if the wound is clean and the blood is fortified with penicillin. They stand the wear and tear of rough usage as soon as nerve supply returns to them, and furnish a bed under which tendons—whether old or newly repaired—will glide. They do not shrink and they grow with the individual, as often seen in grafts which were placed when the patient was a child. They carry hair and all the structures of the skin and do not pigment excessively, as free grafts occasionally do. Skin which has been well transplanted by the pedicle method lies flat without excessive subcutaneous tissue, and its borders are quite inconspicuous and do not abruptly cross flexion creases. One frequently sees poorly made pedicle grafts that show a dome-like swelling from excess of subcutaneous tissue



A B

FIG. 139. Case A. W. Building volar skin on the distal halves of three fingers by the tubular pedicle method.
(A) Pedicle in transit.
(B) Skin in place.

and which often cover only a part instead of the whole of the cicatricial area. They are often thus surrounded by a ring of scar tissue, and the border may be conspicuous and even thickened to keloid or flexion contracture where it crosses a flexion crease. We should err on the side of thoroughness: complete removal of all scar, freeing edges by undermining, and furnishing ample coverage.

Blood supply of a pedicle flap is in the main in two locations. Large vessels are just above the deep fascia, but there is an abundant blood supply close to the skin. For a pedicle the size of a hand we may dispense with the deep layer of vessels except at the base of the pedicle relying on those close to the skin for the flap which is on the hand. Redundant fat is parasitic and should be trimmed off so the graft will be flat. A graft too puffy with fat can be leveled by raising up one half of it at a time, removing the fat. Pedicle grafts are often made excessively thick so they stand out in a grotesque dome, the idea being to furnish ample skin. This, however, except in a few special cases such as clumped fingers, is a fallacy because skin itself will grow to cover at normal tension any area. It is the borders that are unyielding and contract in

stead of elongating It is they, not the skin itself, that hamper motions Great care should be used in planning so that the borders of the graft will never limit normal, complete, free movement of the hand Pedicle skin should lie flat with the hand Too much fat is parasitic, being an additional burden on the blood supply It

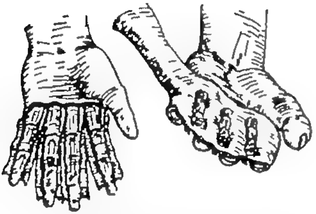


FIG. 140. Covering volar or dorsal surface of all fingers with pedicled skin by what may be called the mitten method. The cicatricial skin of each digit is split down the midline and folded back until that from each pair of adjoining fingers can be everted and sutured. The pedicle opened out is then applied over all, using bolsters tied very loosely to make it dip into the interspaces. The sutures that evert (see text) should also catch a bit of the opposite fat of the pedicle. The pedicle should be ample in size because much more skin is needed than appears to be necessary

should be trimmed fairly thin with the skin, just leaving enough to place a layer between the tendons if needed. Abundant blood supply, as seen on cross section, is between the fat and the skin so it is safe to trim away the redundancy To correct excessive fat in a pedicle requires two operations

Following gunshot wounds or any wound with large skin destruction, reconstruction of a hand usually necessitates a preliminary placing of a pedicle skin graft just as the principle applies to deep repair anywhere in the body

Prevalent faults of pedicles are that they are dome-like, they are too scanty to replace the cicatrix entirely they are made merely as patches with borders paralleling lines of push and pull without regard to the mobility of the hand, and they may not be aseptic.

Hands are prone to stiffen. Besides prolonged splinting and edema, a great cause of stiffening is an open wound The products of this inflammation, even in the course of a few weeks, result in considerable stiffening Therefore, wounds in hands should be closed early by primary or secondary closure or skin grafting The application of this is in applying pedicle skin to a hand. I am convinced that, for a hand, we should never use the open pedicle method, that is, the septic pedicle in which the stem is raw with exposed granulations The open stem of a pedicle is equivalent to an open wound in the hand The lymphatic vessels carry the products of inflammation directly into the hand resulting in very undesirable stiffening which is our arch enemy All pedicles to hands should be rendered aseptic by closure. This can be done by either tubing or skin grafting over all raw surfaces. This makes for clean wounds and finer scars. Neat, careful suturing of pedicles yields clean healing instead of dirty borders It is important also, in order to prevent stiffening, to avoid collections of serum or blood by careful hemostasis placing drains for 24 hours and avoiding dead space, and edema to build about the pedicle a firm pressure dressing that fills in every interstice.

When one is confident in the use of pedicles, various operations on the deeper tissues within moderate limits may be done at the same time as the pedicle graft. This includes nerve suture capsulectomy, excision of deep cicatrix, bone carpentry, and even placing a bone graft such as a thumb post. *Time is thus saved This is not the* occasion by choice for elaborate reconstruction but even so at the terminus of a deep operation it occasionally may be necessary to close by a pedicle flap

Pedicle grafts are of various types pocket graft, flap graft, and tubular pedicle. In the *pocket* type the flap of skin is raised from the abdomen or inner part of

thigh for the dorsum or hip for the palm, and under this the hand is placed, so that the denuded area on the hand is covered by the flap of skin This flap should have two or multiple pedicles to maintain its blood are cut across from the abdomen, either all at once or preferably and safer on suc ceeding days From such an odoriferous septic method we cannot expect to have narrow scars of union between the graft

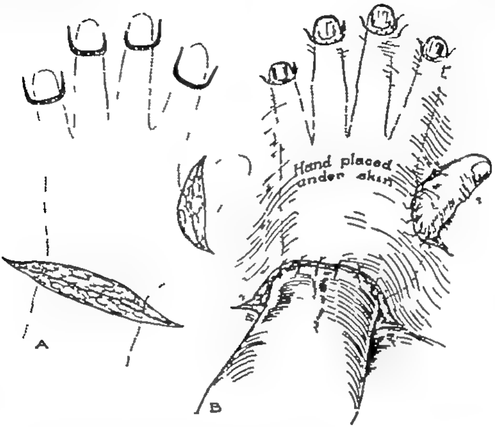


FIG. 141 Pocket graft to cover dorsum of hand and fingers.
(A) Incisions through which the skin is undermined.
(B) The hand is inserted. The skin flap is nourished through multiple pedicles which later may be severed a few at a time.

supply It can be cut to a pattern to cover all digits and the back of the hand as a whole, and cut and replaced two weeks ahead of time for better vascularity The objection to this method is that the wound is necessarily dirty The skin of much of the hand is in contact with the raw under surface from which the flap was raised Compresses and constant care are necessary to keep it clean

It is not practical first to Thiersch skin graft the area under a pocket graft, unless done a week in advance and the pedicle at once replaced, because such grafts usually slough away on account of the excess of infection, and even erysipelas may develop and spread widely over the limb After two or three weeks the pedicles of the skin

and the surrounding skin It is, however, possible later, when the area is clean, to ex cise these margins and obtain narrow ones

Flap grafts are the type used most frequently for forearm and hand, though for elongated flaps covering digits and over complicated surfaces a tube pedicle is better adapted If made with a broad flaring base and according to its blood supply, not longer than two or two and one half to a width of one, previous preparation is unnecessary If made in a direction not paralleling the blood supply, or made in a bizarre shape wider at the end than at the base elongated or interdigitated, the blood supply should be developed slowly by repeated steps, i e , delayed pedicle In these delayed pedicle flaps portions of the borders are successively

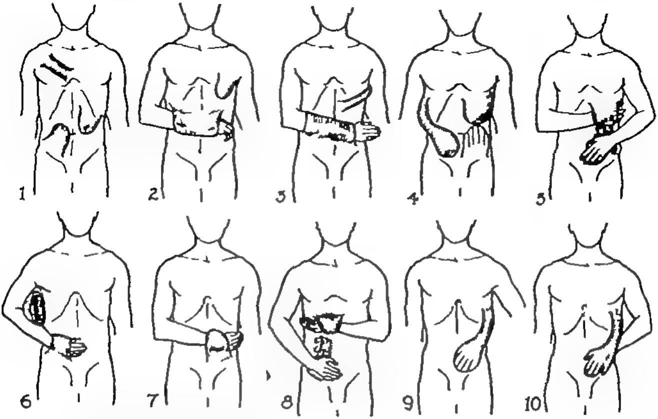


FIG. 142A. Types of abdominal pedicles.
1 Deltopectoral tube, upper and lower abdominal flaps with thoracicoepigastric circulation.
2 Broad flap turned up chest flap
3 High tube. Broad flap turned down.
4 Tube pedicle with pancake expansion. Flap to turn down is interdigitated in stages and applied to hand in 5
5 Flap covering volar surface and interdigitated. One covering dorsal surface.
6 *Method of padding triangle for a pedicle on the near side.*
7 Lower flap pedicle applied.
8 Upper and lower flap pedicles applied. Raw area is skin grafted.
9 *Interdigitated* pancake expansion on a tube pedicle, prepared in stages and useful to cover either dorsal or volar surface of hand on near side.
10 Interdigitated pancake expansion applied to dorsal surface fingers and hand.

cut, undermined and replaced, at intervals of from five to ten days, until the vessels in the base hypertrophy sufficiently to support the whole flap If the graft is applied in the first procedure (pedicle in one) which takes including detachment about five weeks and is the usual method, much time is saved. There is an advantage, too, in applying the hand close against the abdominal wall so the abdominal skin moves with the hand the fixation of the hand to the abdomen can be made simply by elastoplast or adhesive plaster wrapped about arm hand and body

Pedicle flaps are best located in the lower or upper part of one side of the abdomen or lower chest, or may be made to extend all the way across. As the blood supply is vertical, the flaps should be vertical. There is a rich thoracico-epigastric vascular system arising above from the lateral vein and the superficial superior epigastric vessels from the mammary Arteries and veins course downwards to meet those coursing upwards from the superficial circumflex iliac and superficial inferior epigastric from the femoral Sometimes these vessels may be outlined through the skin, though this is not necessary Due to lack of venous drainage more than to lack of arterial blood pedi

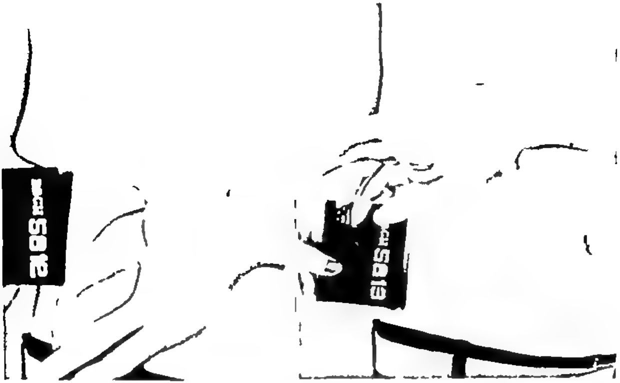


FIG. 142B Direct abdominal flap Bed and stem are enclosed by skin graft. (Courtesy of W H Macomber Lt Col., M.C., Dibble General Hospital.)

cles are lost. There is cyanosis, blistering, thrombosis and finally gangrene Heparin may be of aid in impending thrombosis Flaps may be turned either up or down to fit the denuded area, preferably down in the lower abdomen and up in the upper abdomen If pronation and supination are limited, it may be necessary to use the longer tube pedicle in order to reach The hairy pubic region should be avoided Flaps from the opposite arm or forearm or the acromiopectoral region are available but seldom used.

A pedicle flap should, in addition to its stem, be one-fourth larger than the area to cover as skin retracts Excessive fat should be trimmed off until the graft is flat. The stem of the pedicle should be short. If made long it should be detached in stages The donor area may be closed or partially closed by sliding, undermining freely If, when pulled taut, the skin beyond the margin is still loose the undermining should extend further All remaining open areas of donor site and pedicle are closed with skin graft. Sutures of the margins are left long to tie over pads to keep firm pressure on the grafts, thus avoiding edema and seepage More external pressure is built up by waste, snugged on by adhesive plaster so placed that it may be turned down for inspection. Petrolatum gauze or nylon is placed next to the skin graft.

The hand is held in perfect position on the abdomen, and its limits, radial, ulnar and finger tip, are marked on the abdomen as a check against shifting After the skin is painted with compound tincture of benzoin, broad adhesive is placed around the upper arm and chest, another down the back of the upper arm, around the elbow and along the forearm to around the chest, and two more strips diagonally about the forearm, upper arm and chest The pedicle site is kept free for inspection Padding should not be placed between the adhesive and the arm as it will pack and allow movement partially to pull off the pedicle nor should all be closed in with adhesive plaster as the wounds will become foul from lack of aeration When the hand is attached to the far side of the abdomen only a thin pad is

FIG. 143 (*Above* and *Below*) Stump of hand covered by direct flap All raw surfaces are covered by skin graft. Here it is advisable to have much subcutaneous fat to have enough skin to cover the several digits some of which may be phalangized. (Courtesy of W B Macomber Lt. Col., M.C., Dibble General Hospital)

placed in the axilla, but when it is attached to the near side, the triangle formed by arm and chest should be firmly packed with padding and strapped to the chest for immovable anchorage. The suture lines may be covered with a layer of vaseline gauze. It is important to pack every angle and interstice with wadding held by outside wrappings of elastoplast or adhesive plaster so that the hand, arm and abdomen are as one firm body, impossible of movement. Skin grafts over donor areas and under surfaces of pedicles should, wherever possible, have stents tied over them

In a week walking is permitted only in some cases. In three weeks the pedicle is detached from the abdomen. The stem can be cut off long and replaced on the abdomen. If the stem is cut long on the hand, its blood supply will be jeopardized as an area on the hand will hardly support a similar area of stem It is safer to sever such a stem in two stages This does not hold for tube or delayed pedicles as they have been prepared. It is best to cover most of the donor area at the first procedure and make flaps blunt pointed and broad. Pedicles require early and frequent inspection and constant vigilance against displacement. Periodical soap and water cleansing whenever indicated is good sanitation.

To replace simultaneously the cicatrix on each side of a limb, both by flap graft, two flap grafts are prepared on the abdomen pointing in opposite directions. The two flaps may be made by one broad S-shaped incision

A simpler aseptic method without necessitating skin grafting is the stemless method as developed by Blocker A pattern is made of the denuded area on the hand left from excision of cicatrix and from freeing of skin edges. On the abdomen this pattern is outlined lightly with scalpel. Either the lower or upper half of this area is raised and turned back along a midline crossing the pattern, thus exposing raw surface the shape and size of the pattern. The similar denudation on the hand is applied to this, suturing about the complete circumference of the wound After three weeks the other

A

B

Fig. 144 Case VIII The hand was caught between hot rollers in a laundry mangle, denuding the skin from the whole volar aspect of all of the fingers. In the healing each finger was drawn into sharp flexion contracture by the cicatrix which covered completely the volar surface of each.

The fingers were first united by suture to each other by everting the volar cicatrix and a tubular pedicle skin graft was applied to all the fingers and the distal part of the palm as a whole as shown in (A) Later this mitten was interdigitated and the skin was laid smoothly on the full length of each finger as shown in (B) (Courtesy Jour Bone and Joint Surg., p. 45 Jan., 1932)

half of the flap is detached from the abdomen, cutting along the line originally outlined by the scalpel. This should be done in two stages a week apart, cutting first the sides of the flap and then the end The hand is then also detached from the abdomen to which it had been temporarily sutured in half the circumference of the wound The skin flap, half of which by now has grown to the hand, is then laid down flat to cover the remaining half of the denuded area on the hand

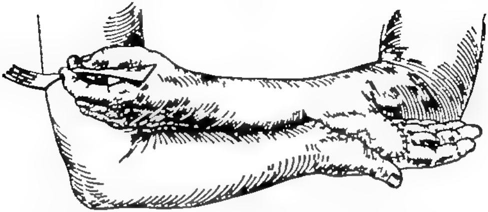


FIG. 145 The skin from the opposite forearm utilized as a flap pedicle to the other hand allows the patient to be ambulatory and to feed himself with his good hand. (Rarely used.)

Dressings are closely packed all around to prevent edema and to hold the tissues firmly together Two small rubber tube drains may be placed with strings extending out for removal on the following day

The tubular pedicle has some definite advantages over the pocket and open flap pedicle grafts. The first is that it is aseptic in contrast to septic, because there are no raw areas exposed. Therefore this method gives narrower and more inconspicuous borders and less stiffening in the hands than do the septic methods. Another advantage is that the tubular pedicle is longer and so allows much more freedom of attachment during the two or three weeks the limb is fastened to the trunk Also, it fits into awkward places and shapes where a flap would not. The fourth advantage is that the tubular pedicle can be waltzed from one place to another about the body like the progression of a measuring worm For this, the wrist is a convenient vehicle. The more often the pedicle graft is waltzed, the better becomes its vitality Considerably more technical detail is required to use the tubular type of pedicle graft successfully To make a pedicle fit a hand one may swing a flap of normal skin to line a cleft or cover part of the denudation so that the area to receive the pedicle will be better in shape or location. Whatever type of pedicle graft is used it is safer to proceed in stages, so as gradually to hypertrophy the blood vessels in the one pedicle which is to be the base Each step requires from one to three weeks depending on how radical is the change in blood supply

It is common to find a wide, unsightly cicatricial area left at the donor site which could have been avoided and is entirely out of proportion in importance to the site which was repaired. In order to remedy one scar we should not produce in another area a worse one Oblivion to the cosmetic side of surgery is unfortunately too prevalent.

TECHNIC OF TUBULAR PEDICLE GRAFT The pedicle should be cut in such a way as to leave the least scar in the donor area. Those pedicles which are made longitudinal to the neck or the abdomen leave scars that are atrocious. If the pedicle on the side of the abdomen is made exactly parallel to the

FIG. 146A. (*Above*) Direct closed stemless abdominal flap showing incision for pattern before delayed detachment. (Courtesy of L. D Howard, Lt. Col., M.C. Wakeman General Hospital.)

FIG. 146B (*Below*) Direct stemless abdominal pedicle. Incision for pattern is shown preparatory to detachment in two stages. (Courtesy of L. D Howard Lt. Col., M C., Wake man General Hospital.)

creases (that is, transversely), it will leave the least scar, but the pedicle will be somewhat taut. Here, therefore, a compromise is made and the line of the pedicle is usually a little oblique, which gives a much slacker pedicle. A useful site for a pedicle is the acromiopectoral region, where it can be made paralleling the skin creases. All who have made tubular pedicles have experienced necrosis and separation of skin edges at the angles If the pedicle is made in the simplest way, that is with two parallel incisions, each angle will have entering into it four arms of incision, and the suture line of the pedicle will directly overlie that on the abdomen The result will be that

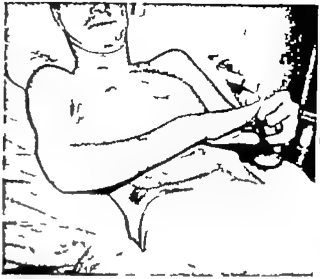


FIG. 147 Direct flap pedicle to fore arm to replace cicatrix preliminary to tendon transfer All raw surfaces have been skin grafted.
(A, B C, D and E) Showing successive steps. (Courtesy of W H Macomber Lt. Col. M.C., Dibble General Hospital.)

A

B

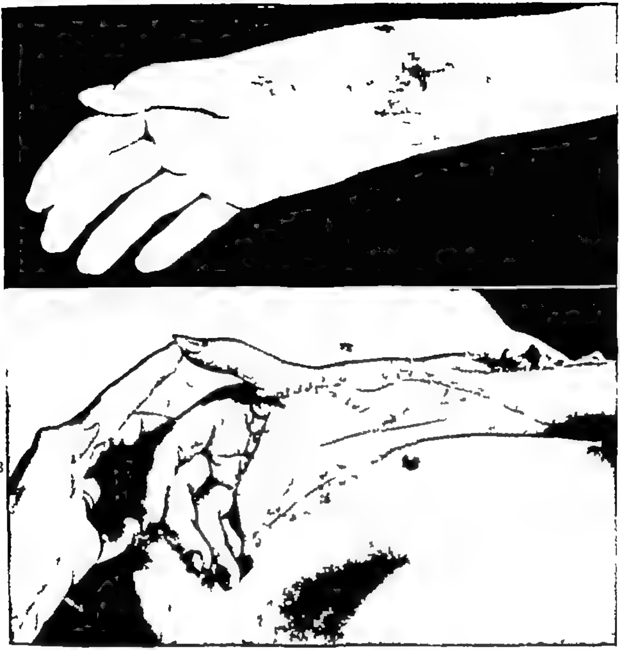
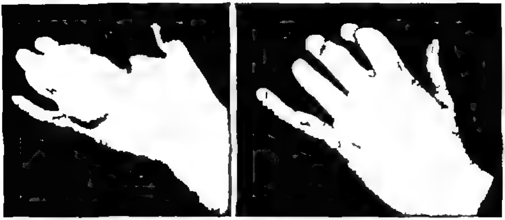


FIG. 148 (A) Defect from gunshot wound of all tendons on radial side, median nerve and part of radius and carpus. (B) Direct abdominal flap applied skin grafting raw surfaces. Detachment from abdomen was done in two stages. Partial incision across flap is shown. (C) Result. (D) Flexor tendon grafts from the long extensors of the toes were placed in all five fingers motivated by the brachialis anticus muscle. Opposition of the thumb was by the flexor ulnaris and adduction of the thumb by a tendon loop transfer from the extensor communis of the index finger (Courtesy of William H. Frackelton Lt. Col M.C., Beaumont General Hospital.)

C

D

Fig. 149 Case A. M. From a hot roller the fingers had grown to the palm (A) Fingers were freed with a scalpel, partially extended, skin grafted, and then further extended by slow traction. Volar skin from each finger cut down the center was folded back, joined everted to form a mitten, and a tubular pedicle from abdomen was applied over all. (B) Pedicle placed. (C) Interdigitated. (Courtesy Jour. Bone and Joint Surg., 14-44, No. 1 1932)



A B

FIG. 150 (A) Poor pedicle graft. Too redundant, scanty and with webs.
(B) Same improved by raising up, removing excess of fat, and re placing Webs restored by laying points of skin through clefts.

the angles break down and that the suture lines which overlie each other will reflect back and forth like two burning logs in the fire, and so prevent good healing

The following technic, which produces only three arms meeting at the angle, and rotates outward the suture line of the ped icle away from that in the abdomen, will give much better healing The cuts for this are simple, at each end of the lower incision a short diagonal incision is made, running downward and toward each other for about an inch and a half, making a point of skin at each end. The skin all around is then undermined, keeping exactly in the cleavage plane between the deep and super ficial fascia and extending for a foot or more above and below the pedicle and also somewhat beyond each end of the pedicle. This thorough freeing will allow the skin edges to come together beneath the pedicle and to be sutured without tension

Each of the two pointed flaps should first be sutured by its point to the end of the upper incision of the pedicle, and the abdominal wound the length of the pedicle closed under the pedicle. The edges of the pedicle are sutured to each other to form a tube, after first placing two guide sutures 1¼ inches from each end of the tube respectively and a third at the middle Commencing at the point of each of the flaps, the upper border of the pedicle is sutured down the adjoining border of each pointed flap for the width of the pedicle and to the first guide suture. The remaining short arm of incision at each end is then also closed by suture.

It will be seen that the suture line of the pedicle is rolled outward so that it does not

A B C

FIG. 151 (A) Large cicatrix from gunshot wound.
(B and C) Replaced by large expansion flap on end of tube pedicle. Note zigzagging on ulnar border to prevent keloid formation. Much reconstruction was done later (Courtesy of L. D Howard, Lt. Col. M.C., Wakeman General Hospital.)

A B C

FIG. 152 Case E. R. S In 1929 from cumulative exposures to the x ray both hands of this surgeon were badly burned, resulting in nine years of pain, ulcerative dermatitis infection of bone and joints, ankylosis and atrophy

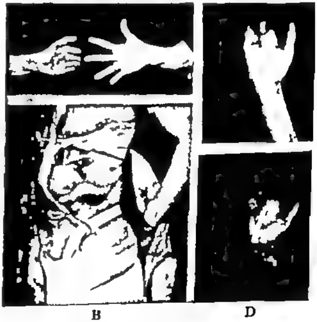
(A) Atrophic, bird-like fingers and pedicles which were to replace the damaged skin over the dorsum of all the fingers. This was done in a series of operations.

(B and C) Fingers now are all covered with good skin and have loosened up with return of nutrition. Ambition has replaced discouragement and now he is able to operate.

face the abdomen, and a point of skin is present lying across each of the angles between the pedicle and the abdomen. Only one border of this triangular flap is in a dark, covered place. A pad of gauze separating the pedicle from the abdomen aids in keeping the skin surfaces apart and in protecting this vulnerable line of suture Even so, it has often been found that this suture line has sloughed out en masse, evidently the sweat and infection from the dark angle followed in along the stitches, causing necrosis of the suture line. To obviate this, we use as suture material stainless steel wire, and sew this arm of the incision subcutaneously without any stitch in the angle penetrating through the skin which could carry in infection. The No 34 wire is fastened with a shot over a button at each end. The remainder of the suturing is done with No 38 stainless steel wire. It is first necessary in closing the abdominal wound to place wide, encircling retention sutures of No 30 wire to relieve the strain on the suture line. These stitches each catch the deep fascia in their encirclement, so as to obliterate dead space and stop slithering

It is essential to place a tube drain through a stab wound at each corner of the wide area of undermining of the skin. This stab wound should be made only superficially with a pointed scalpel, and carried in through the fat by a spreading hemostat, because in some cases a deep stab of a knife has cut a deep vessel, resulting in large hematoma.

A C



B D

FIG. 153 Case J D

(A) Right hand was drawn into a hot mangle resulting in cicatricial stubs of fingers to the distal part of the hand rendering the hand unfit for work.

(B) Pedicled skin graft from abdomen.

(C) Pedicle in transit.

(D) Digits covered with good skin. Index and long are as one.

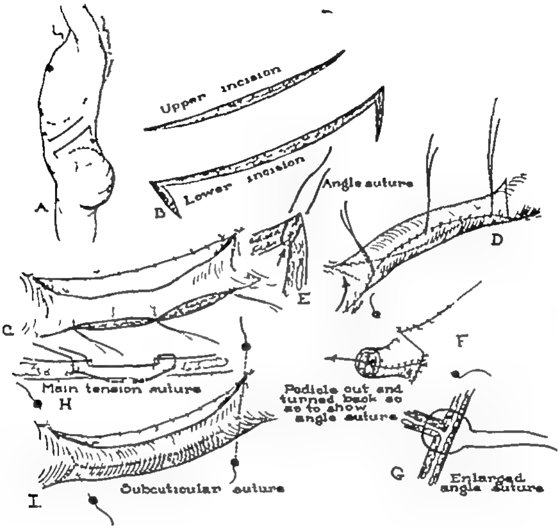


FIG 154 Preparation of tubular pedicle.
(A) Shows incisions wide area of undermining (dotted) four points for rubber tube drains.
(B) Incisions to have a flap of skin in each angle and to place the two main suture lines so that they will not appose each other.
(C) Three guide sutures are placed on the pedicle. Main abdominal incision is closed as in (H) and the tips of the flaps are fastened as in (E)
(D) Suture lines do not appose.
(F) A subcuticular suture is used in the angle to avoid channelways through the skin that would carry infection. By the flap method the vulnerable X juncture is replaced by a T juncture as shown in (G) and (I)

It is, of course, essential to obtain good hemostasis on closing this extensive abdominal wound Before the pedicle is made into a tube, sufficient fat should be trimmed away from it with sharp scissors so that its edges will approximate to each other without any tension. A pedicle which is tight at the middle or at its ends is sure to slough. If, however, we trim away too much fat from the pedicle it will be too baggy and will fill up with hematoma.

Instead of making the two angle flaps on the same side of the pedicle, the rear one, if made above the pedicle, will bring the pedicle more vertical and, hence, make it looser (Howard) Another method is to omit these flaps, but to stagger the angles to make a continuous suture line The lower cut may be longer so as to roll the pedicle out as described in making the tube pedicle in one stage Also the incisions for the pedicle may be curved to give more slack and staggered at the end to avoid X junctures.

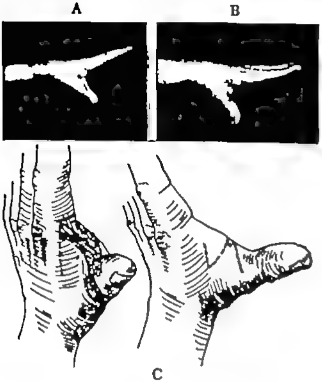


FIG. 155 Case C. B
(A) Keloid web contractures from an electric flash burn.
(B) Correction by a Z plastic.
(C) Procedure.

The after-care of the pedicle is important. The suture lines are kept rolled apart and as many layers of gauze are kept between pedicle and abdomen as possible without causing too much pressure under the pedicle. Formerly, each day the angles of the pedicle were washed with soap and water and dried and powdered with boric acid to prevent infection from sweaty, apposed skin from breaking down the suture line. With powdered sulfonamide, days or a week may pass without washing. Our aim is to obtain 100 per cent healing. This conserves the time of the patient, often allowing the pedicle to be transferred at the end of two weeks. Three weeks are preferable, however, as better blood supply is assured. The patient should remain in bed throughout the first two weeks, because the motion incurred in walking might separate the skin at the angles of the pedicle, and if this happens he should remain in bed until these angles have healed. To transfer a pedicle before all raw areas have been covered means that one is courting failure.

A tube pedicle should never be made crossing the midline of the body, because only a few blood vessels transverse this line. If, on separating one end of the pedicle on the abdomen a flap of skin for extra good measure is carried along with the pedicle, this flap often necroses at its end. An excellent method, however, to avoid this and to increase the area of skin transferred, is at the end of two weeks to cut such a flap of skin as a pancake extension of the pedicle and raise it up from the abdomen and replace it. One should not, however, at this stage detach the base of the pedicle itself, as through this runs the nourishment for the newly constructed flap. Two weeks later this flap and the base of the pedicle can be detached from the abdomen and transferred. It will be found to be quite viable to its very tip. If a tube pedicle is short and thick, a pancake may be raised with one end of it directly without any step cuts, and another pancake may be taken with it when it is detached from the abdomen. As a rule, if a pedicle is 8 inches long it should not be less than 2 inches wide, this being the proportion whatever the size. If greater length is needed a central part of one of the borders is left uncut for central blood supply (method of Webster), but severed after two weeks. By using several intermediate pedicles a very long thoracicoabdominal tube can be built. Later these secondary pedicles are severed until there is one long tube. By a pad beneath, a healed pedicle may be gradually elongated.

In transferring a pedicle to the hand, the former is severed from the abdomen at whichever end will make the easier and more natural connection with the hand. Any twist or strain of the pedicle will result in necrosis. After closing the wound in the abdomen by undermining freely, using retention and approximation sutures and usually one small drain, the length of the pedicle to be attached to the hand is opened out, excising both the linear suture

A B C

FIG. 156 Tubular pedicle on abdomen
(A) Pedicle is loose by being slightly oblique.
(B) Flaps of skin lie across the angles.
(C) The two suture lines do not appose each other This insures against dampness and infection being reflected between them.

line and the cicatricial core of the pedicle. Enough fat is trimmed away from the pedicle, using curved flat scissors, so the skin will lie flat but not enough is taken to jeopardize a good blood supply to the pedicle throughout A few light longitudinal incisions in the fat allow the pedicle to unfold.

It is well to place a few tiny rubber tube drains beneath the pedicle on the hand, lest a hematoma should form and spoil the result. There should not be the least tension, especially across the pedicle. The tip of the pedicle should not be too pointed, and it should be slightly redundant to insure enough material being present in case of necrosis of the edge Usually only part of the area to be covered in the hand is at this stage covered by the pedicle, but it is so planned that after two weeks, when the other end of the pedicle is freed from the abdomen, it can be laid down over the remainder of the part in the hand to be covered For the first contact at least three inches of the pedicle should be placed.

If it is seen that the skin beneath the

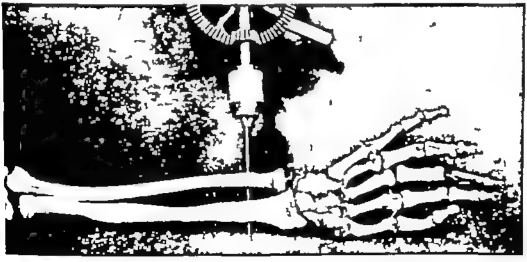


FIG. 157 Method of maintaining fixed supination while a pedicle skin graft is attached to the hand. Useful also in arthrodesis of wrist and other conditions of forearm bones, to hold position of pronation or supination without the aid of a cast to the axilla with the elbow at a right angle. In the case of arthrodesis the ends of the wire should be embedded in the plaster cast.

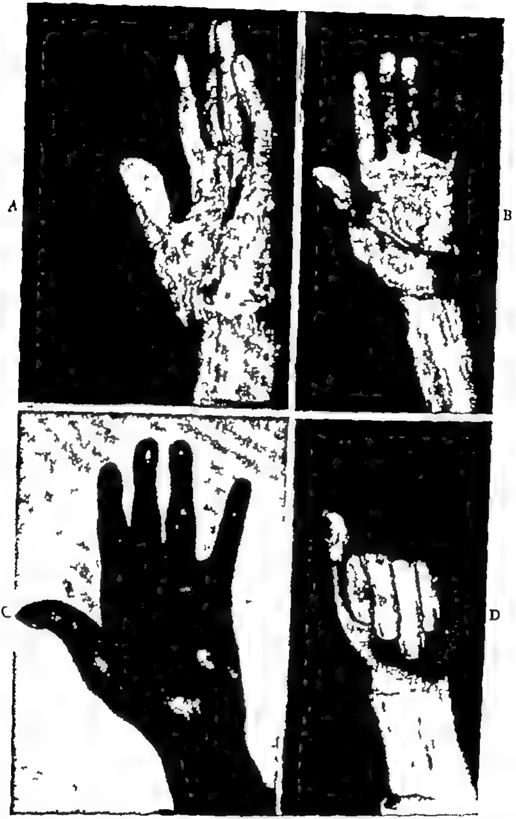


FIG. 158 Case R. W (colored) Fourteen months previously hand was badly burned in a gasoline explosion, taking four months to heal. A stiff hard keloid covers base of thumb and palm, drawing thumb in adduction, preventing flexion of wrist, and causing pain as shown in (A) The little finger had a slight contracture by a band running in the wrist. Finger joints were stiffened so that fingers lacked an inch of touching palm.

Operation. A zigzag plastic relieved flexion band of little finger The keloid over thumb and base of palm was excised and in its place was sutured skin from the side of the chest from a previously prepared tubular pedicle. Finger joints were mobilized by the slow traction method. In (B) is seen the skin graft in place, but the linear scar running to thumb, being under some tension, is forming a keloid and adducting thumb This was excised and tension relieved by a zigzag plastic which allowed thumb to abduct, as shown in (C) Little finger is straight. In (D), taken seven months after operation, is seen degree of flexion and absence of keloid. (Courtesy Surg., Gynec., and Obstet., 39.264 Sept., 1924.)

pedicle is on a tension, a relaxing strap should be used for a week or so, which runs around the neck and shoulders and under the knees, buckling the patient forward

The arm and hand should be firmly fastened in place so that their position will not shift in the patient's sleep, kinking or straining the pedicle enough to cause necrosis. Formerly, I used many adhesive straps on the arm and body, continued with tapes for tying to each other, and in addition a web strap and buckle in a figure-of-eight around waist and thigh as an anchorage. In this way the hand and arm were so pulled in all directions that they could not move. The tapes, each of which had a purpose, could be tightened or loosened as required. It was found that far better immobilization could be maintained by using plaster of Paris. Instead of encircling the body with this, as with a body cast, the plaster may be fastened to the abdomen and arm by broad adhesive strips laid first on the skin. Each of these strips has attached to it, passing through holes, many short lengths of cloth tape. As the plaster of Paris slabs are laid on the abdomen these short lengths of tape are folded into them A cast, half encircling the body, is thus made, which will not slip on the skin, and it includes the arm but leaves the pedicle open and free for dressings. The cast about the arm is placed directly on the skin, free from padding, but an open slit is left along the forearm and hand lest the cast needs to be spread to relieve pressure. Two web belts encircle the plaster and the body Occasionally, with this arrangement the patient is allowed to be ambulatory Fixation for some tube pedicles may be sufficient by adhesive plaster as in the flap method Where, though, the hand must be held exactly right, plaster of Paris is preferable. The arm and abdominal members may be constructed separately so the hand can be perfectly adjusted to the pedicle, and then the two casts may be joined together Our habit now is to use well padded, circular

A C B D

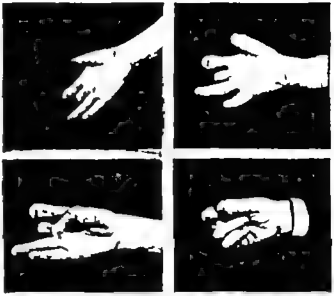


FIG. 159 Case J D A one-pound projectile exploded in his hand. What remained of the first three digits was very cicatricial Webs drew them together

The cicatrix was replaced by good tubular pedicled skin from the abdomen, first to the thumb and then swung to the index finger Webs were relieved by placing good skin across the clefts. A useful hand was obtained.

(A) Preoperative.

(B C, and D) Postoperative.

casts, sometimes including a thigh in youngsters If the forearm must be held strongly supinated, a heavy Kirschner wire drilled across through radius and ulna is used.

In transferring skin by the pedicle method we are frequently straining the last degree of vitality of the tissue. Eternal vigilance by the surgeons and nurses is essential for the safe healing of a pedicle. Special orders of caution should be written on the chart, to determine and report on the circulation and to discover early any tension, compression, torsion, or kinking that may occur It is well to be overcautious and keep a margin of safety, so that on visiting the patient the evening of the operation or on some following day one will not be confronted with signs of poor circulation. Tissue that is overstrained is white or too pale at the time of operation Extra time spent then in relieving circulation is well repaid, for on the following day the white tissue may be black—"from ivory

to ebony" One may see a black border of necrosis backed up by a wide zone of red, swollen tissue which may show blistering This red, dusky, boggy area is from local thrombosis from too much lowering of the circulation. *If the skin is merely red and blistered it may live, though its quality may suffer* Necrotic skin does not blister Warm compresses *will help it, but extreme* caution should be taken whenever using heat, by lights or compresses on pedicles, because without nerve supply and with lowered circulation, they are exceedingly vulnerable The upper limit of temperature should be 105° F

When actual necrosis occurs in a skin flap, the surrounding wound becomes infected and does not do well The necrotic mass acts as a nutrient focus disseminating infection, and much time is wasted in waiting for it to slough away Therefore, when real necrosis is discovered it is best, just as in treating a pressure sore from a cast, to excise it and do an immediate Thiersch skin graft. If the end of a pedicle necroses and must be detached, it may be immediately reattached to the hand as a shorter pedicle before infection occurs A free, blind end of a pedicle sutured over often necroses a little at its end. Rather than suture it over it is better to imbed it in some nearby skin, in which case it will obtain additional circulation and will live.

In transferring a pedicle for purposes of waltzing, a semicircular cut is made in the *skin to receive it, and this flap is folded* back, providing a raw, circular area to which the end of the pedicle is attached. Exact coaptation without intervening hematoma is obtained by means of several running stainless steel wires No 34, that catch alternately each opposing surface and are fastened on each side by shot on the surface of the skin. Greater blood supply may be obtained by raising instead of a semicircle *of skin, a long tongue or broad flap* and inserting it down the seam of the tube. On again detaching the pedicle, this flap is replaced To carry a large tube, a broad attachment is needed and if the tube, in turn, carries a flap, the attachment should be similarly broad.

With a tube pedicle one may cover several digits, swing the pedicle from one digit to another, or split the pedicle to cover two at a time.

Covering All Fingers at Once

If all volar surfaces of the fingers are to be covered *at once, the cicatricial skin of* each finger may be cut along the midvolar line and folded to the side, where it is sutured with eversion to the similar flap from the adjoining finger This converts the hand into a mitten, over which a broad, redundant flap of pedicle can be placed longitudinally or transversely To cover similarly the dorsum of each finger the incisions are made along the dorsal surfaces. Later the interdigitations are made. It is usually found that the skin has so shrunken that for the last finger the base of the pedicle must be swung around to cover it.

A more satisfactory method is as follows Raise and replace in stages a pancake flap *either as part of a flap pedicle or a tube pedicle, interdigitate it and suture it* back in place. The hand is not converted to a mitten, merely denuded and the interdigitations are sutured over the respective fingers The base of the pedicle may, if needed be used to cover palm or dorsum with or without a separate attachment. (Figs 140 142A, 144, 149)

Still another method, occasionally useful is to fix the denuded fingers widely spread on a splint, and then cover all of their volar or dorsal aspect with a flap pedicle The hand is turned over and the raw areas of the pedicle between each two fingers is covered over by skin graft. In the next stage, the pedicle flap is interdigitated and the ribbons of skin are sutured into the sides of the *fingers.*

Tube Pedicle Without Undermining A simpler preparation of tube pedicle in

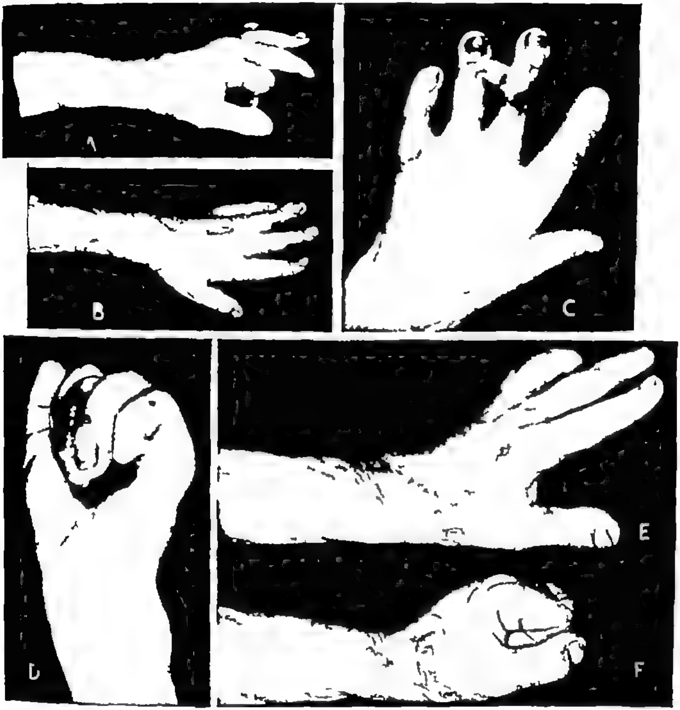


FIG. 160 Case C. P Seven months previously hot lead ran over the left hand and forearm resulting in a tough thick keloid over the dorsum of fingers, hand, and forearm and in webbing of the fingers for one and one-quarter inches beyond the knuckles. The movements of the wrist are much limited the thumb is held in adduction and extension, and the fingers are drawn into extension. The last three fingers are covered with thin red scar adherent to bone and tendon and preventing motion of the joints. The nourishment of the hand is poor because of the ischemic effect of the contracting scar (A) shows the inability to close the hand and (B) the condition of the hand before operation.

Operation. The scar tissue was excised and by a series of tubular pedicle skin grafts from the chest was replaced by good skin (C) shows the method of "waltzing" a pedicle, originally from the chest, from the ring to the long finger resulting in the flexible skin and joints shown in (D) (E) and (F) show the degree of function gained All joints now have good range of motion. The hand and forearm are covered with flexible skin throughout and good nutrition has returned (Courtesy Surg., Gynec., and Obstet., 39 265 Sept., 1924)

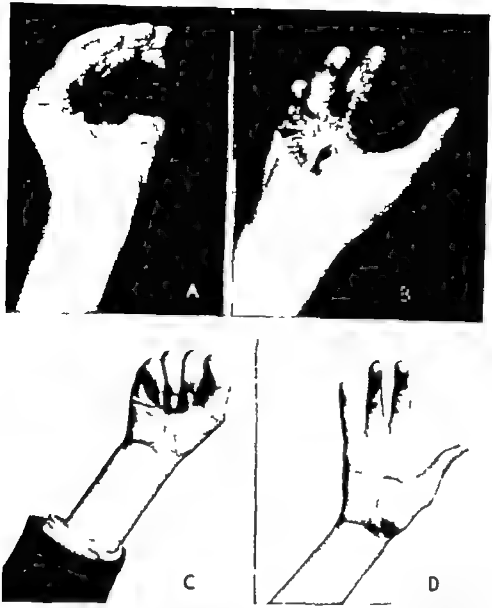


Fig. 161 Case G T., aged 8 Scar contracture due to burn from stove at age of 2 (A) and (B) show limit of extension of the thumb and fingers.

Operation. The scar tissue was excised the hand was placed in extension on a splint and a skin graft from a tubular pedicle on the chest was used to cover the denuded area. (C) and (D) show result. (Courtesy Surg., Gynec., and Obstet., 39:263 Sept., 1924)

which undermining is not necessary and a fairly cosmetic scar is left is to raise the strip or tube through two parallel incisions and in split skin graft underneath it. The skin graft should reflect around each angle to cover also the small triangular raw area under each end of the tube, thus eliminating poor healing in the angles For narrow tubes the abdominal skin should be closed beneath by undermining, but for tubes of large diameter the skin graft method is much preferable. To prepare a tube pedicle by either undermining or by skin graft requires about an hour

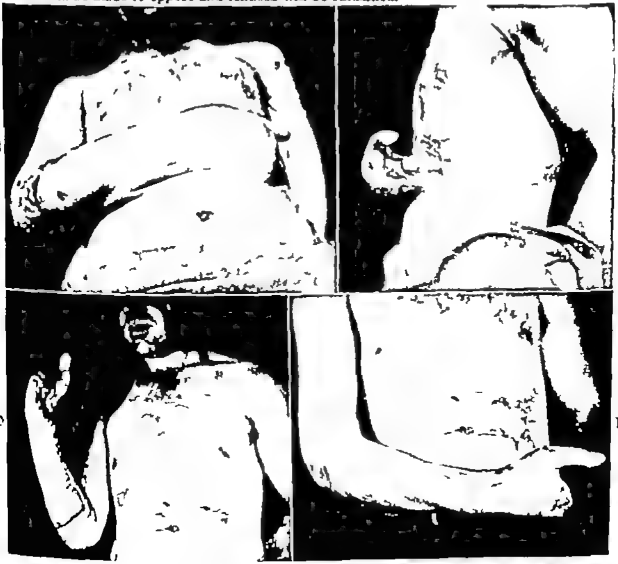
Dressing such a pedicle is important. The least hematoma spoils a skin graft. First petrolatum gauze covers the graft and angles under the pedicle, then flat folded gauze. A gauze roll parallels the pedicle on each side. Gauze or waste fills in all angles and the whole is firmly held in place over pedicle and all by adhesive

A

FIG. 162 Three years ago the right hand and forearm were caught by a belt against metal at 360° and held there 20 minutes rendering the limb useless.

(A) Preoperative appearance.
(B) Giant pedicle flap applied directly
(C) Side view All raw area is skin grafted.
(D and E) New covering over most of the forearm to around the thumb cleft. Later the thumb will be made to oppose and tendons will be furnished.

B C



D E

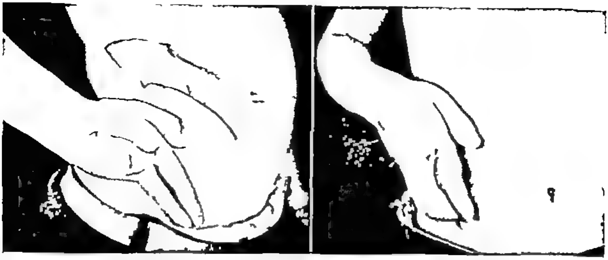
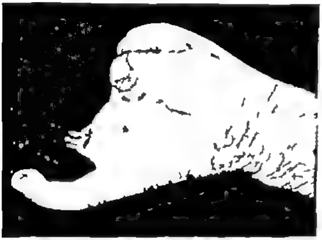


FIG. 163A (*Left*) After loss of two central rays cicatrix drew hand together (*Right*) Cicatrix replaced by pattern expansion on end of tube pedicle Pedicle was folded over palm Note wire to hold metacarpals apart. (Courtesy of L. D Howard, Lt. Col., M C., Wakeman General Hospital)



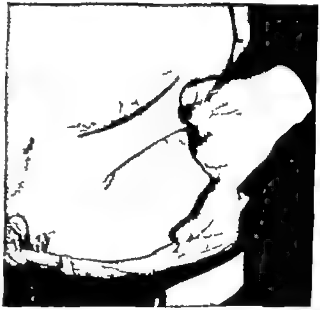
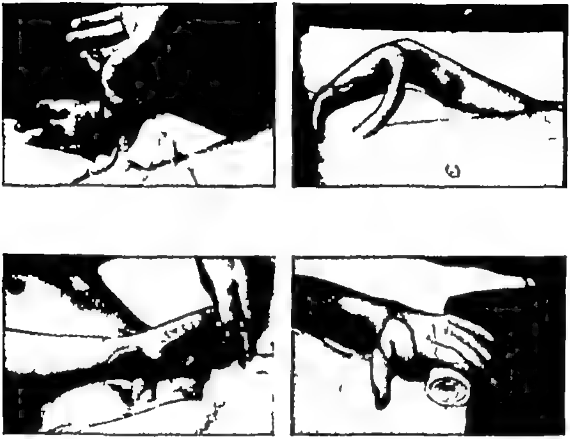


FIG. 163B Result of frostbite in air plane. Healed with split graft and later pedicle reconstruction. The hand may be made useful by excising the second ray phalangizing the thumb with a wide deep cleft, elongating the thumb by pedicle and bone graft and doing an angulatory rotary osteotomy on the base of the fifth metacarpal to make the little finger oppose the thumb (Courtesy of L D Howard, Lt. Col., M.C., Wakeman General Hospital.)

plaster By skin grafting rather than closing by undermining a much larger tube pedicle can be made, such as 15 x 9 inches, and the scar is not too deforming

Tube Pedicle in One Stage Taking advantage of the rich vertical blood supply in the lower abdomen, Darrel Shaw succeeded in making and applying many tube pedicles in one operation A blunt flap in ratio 2½ 1 was raised with the superficial inferior epigastric vessels in its base. It was then tubed, applied to the hand and the denuded area was closed by undermining and drawing the skin together to leave a vertical scar The tube could be rotated without twisting 90 degrees either way to fit the hand if one arm of the incision were elongated and in the closure of the skin margins were sufficiently staggered. The open part of the pedicle faced to the side of the longer incision according to the amount of staggering The pedicle was severed in

PLATE 2



A B C D

(A) Double pedicle abdominal tube applied following excision of severe cicatrix of palm with extensive loss of thenar muscles, flexor tendons and nerves. The tube was applied to the wrist when divided.

(B) Application of a double pedicle tube to a severe injury of the hand and forearm.

(C) One-stage single pedicle abdominal tube applied to the wrist. At the time of application the ends of the divided median and ulnar nerves were overlapped by suture. At the time of division the nerves were sutured.

(D) One-stage single pedicle abdominal tube applied to web space to relieve contracture between the thumb and index finger. At the time of division the tube may be easily draped into the palm if required. (Shaw D. T., and Payne, R. L. Repair of surface defects of the upper extremity. An. Surg. 123:722.)

A

Cicatrix from burns replaced by thick free skin grafts. Case 1 (A, *Left*) Limit of flexion showing blanching (B *Right*) Extensive skin grafts supplied.

C

D

(C, *Left*) Postoperative. Complete flexion without blanching (D *Right*) Excellent appearance. Veins show through skin.

E

F

(E, *Left*) Specimen removed from this hand. (Courtesy of G. V Webster Capt., M C, U S N Bethesda, Md.)

Case 2. (F *Right*) Perfect result in a similar case of both hands. (Courtesy of Paul W Greeley Capt., M C U S Naval Hospital, Oakland.)

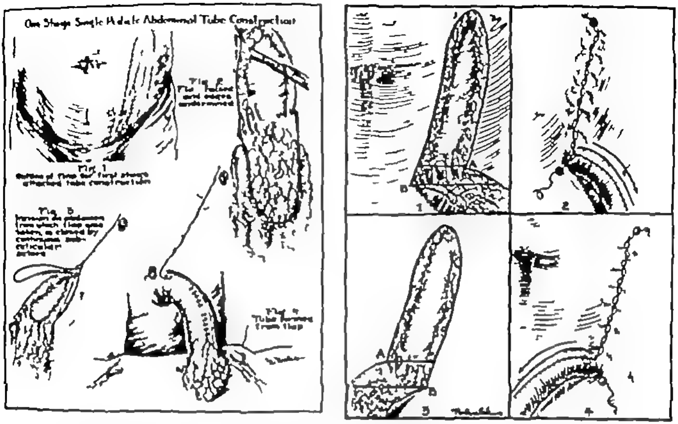


FIG. 164 Tube pedicle made and applied in one operation (Shaw)
(A, *Left*) (1) Flap is made in line of vessels. (2) Undermining to close. (3 and 4) Stainless steel wire is used.
(B *Right*) Methods of rotating pedicle either way (1 and 2) To left. (3 and 4) To right, by making one incision lower and staggering. (Courtesy of Darrel T Shaw, Capt., M.C., and Robert N Payne Capt. M.C., Jour Surg Gyn. and Obst.)

three weeks only if it covered most of the defect and after a longer time, or in stages if used to build a thumb, because there has been insufficient time for the circulation to compensate. A tube pedicle prepared in one stage is, of course, not the equivalent of the usual tube pedicle and so is not as viable because the principle of the tube pedicle is that there is a pre-prepared longitudinal blood supply The tube pedicle in one stage is nothing but a tubed flap

Operating Beneath a Skin Graft. In operating after a pedicle graft has been placed, it is heresy to incise directly through the graft. Instead half of the border scar should be excised and the graft rolled back If tendons are adherent beneath, a slice of fat may be folded down from the under surface of the graft and laid across under the tendons In placing new tendons under a graft for gliding they may by tunneling be passed directly through the fat In operating through a free skin graft, it is necessary to incise directly through it, for we cannot turn this back as a flap unless it has thick, vascular, subcutaneous tissue beneath it.

FREE SKIN GRAFTS

Free grafts are either of full thickness or else of partial thickness, ranging from thick to thin split grafts The great advantage is that they can be applied at one operation, thus saving the patient weeks of hospitalization and the inconvenience of the step operations and attachment of the pedicle graft They are easier to use on children than the pedicle grafts. Unless the full thickness is taken the donor area need not be closed. Thin split grafts will take even on a granulation surface. Full thickness grafts furnish good quality of skin if they are placed on a good bed of subcutaneous tissue. Disadvantages of free grafts

FIG. 165 Case P W Full thickness skin graft from abdomen that pigmented.

are that they need a good vascular bed The cicatrix left from infection is not suitable. They are devoid of subcutaneous tissue and are not so durable as is normal skin in parts which receive wear Tendons will not glide under them. They shrink especially if thin and often pigment. Free grafts are adaptable for shallow superficial cicatrices, such as those from burns, but are less so over the cicatrices from infections which were produced from within.

In placing free grafts, as with pedicle grafts due regard to the movements of the hand will guide us to refrain from placing the graft borders in lines of push and pull Patches are put together with transverse not longitudinal junctures In the fingers the borders should be midlateral or they will thicken and contract, and should be zigzagged and wavy when in lines of irritation

Homografts may take, but melt away in two to six weeks. It is of interest that Medewar found that a graft of any tissue was successful between his inbred white mice

FULL THICKNESS GRAFTS (WOLFE GRAFT) Full thickness grafts will scarcely grow over tendons, bones, or joint ligaments, nor will they grow if there is gross infection present, such as is always found in granulating tissue. They will sometimes take on the bed of a freshly excised leg ulcer A vascular aseptic bed is desirable. The usual source of full thickness grafts is the abdominal skin, but the inner side of the thigh and the arm and that just above and below the clavicle furnish a thin fine quality of skin that is useful in certain places such as over the dorsum of a finger, but rarely necessary for the hand. The scrotum is a useful source for small grafts, though it usually has a tendency to pigment. Many full thickness grafts are prone to do this. Some become black, some brown, some sere yellow, but the majority remain the natural color of the skin. In persons with the tendency to tan darkly in the region usually covered by clothing, one can expect pigmentation of these grafts when placed on the hands or face which are always exposed A full or three-quarter thickness skin graft from good, pliable skin will make better skin and contract less than a piece of split skin of the same thickness but taken from thick skin such as over the back From tough skin tough skin is generated. Care should be taken in placing a full thickness or even a split graft not to have its border cross a flexion crease in such a way that it will become a keloid.

Full thickness grafts require three weeks or more to heal Frequently during healing they retain their pink color and are clearly well vascularized Often, however, during the healing their surface turns brown or black, but if one keeps the limb immobilized long enough this surface necrosis will crust away, showing good, pink, vascular

skin beneath Some grafts in part may merely turn red and blister Dead skin does not blister, so if we give these areas a chance they will eventually show good vitality The skin of the blister should not be removed, but merely pricked and used as a dressing If removed, the skin beneath will necrose

A simpler method of taking a full thickness graft and covering the defect is to use the Padgett dermatome, set for full thickness (032 to 045 inch) When enough skin is cut for the graft, the dermatome is reset for a thin graft (015 inch) and the cut is continued for a similar area The thin graft is laid over the area from which

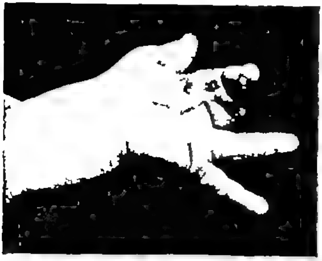
A B C

FIG. 166 Case J B
(A) Flexion contracture of first three fingers in child from placing hand on a hot stove.
(B and C) Cicatrix was excised. The hand was placed on a spreading splint in the opposite position and covered with two-thirds thickness skin graft.

TECHNIC A pattern of thin lead or tin foil is cut as a pattern of the place to be covered and laid on the abdomen The pattern is not made from the cicatrix, but from the denudation after the skin edges have been undermined and allowed to retract The graft should be the same size as the area to be covered, because the lymph vessels then remain open and the cells thrive best at normal tension A site is selected on the abdomen corresponding to that of an appendectomy incision, and the skin is removed in an ellipse so that the wound will close readily to a straight line. The ellipse can be a little narrower than the pattern if it is also a little longer The skin is removed with a generous layer of subcutaneous tissue, the surrounding skin is undermined next the deep fascia, slid together, and sutured, catching the deeper layers with the retention suture so they will not slide and provoke hematoma. Holding the graft tensely over the pulp of the finger, all of the subcutaneous fat is clipped away with sharp thin-bladed scissors.

the full thickness graft was taken Keloids may develop in those susceptible when the cut is deep in the derma and not when superficial I saw a case of carcinoma which developed in the donor area

The graft is sutured in place, preferably with No 38 stainless steel wire. It is essential first to immobilize the hand on a splint or in plaster, because any motion will interfere with healing This must be continued for three and sometimes four weeks Another essential is to apply mild, even pressure to the graft. This may be done as described on p 204 by glycerine sea sponge sheet sponge rubber or wax stent. The whole hand and splint, with the exception of the area of the graft, should then be enclosed in plaster of Paris A sheet of wax paper is then laid over the opening in the plaster and a slab of plaster laid upon it for a lid Children especially need protection by plaster The graft is not inspected until after the tenth day, and after that at intervals of several days to a week A glass slide for a window may be inserted in the



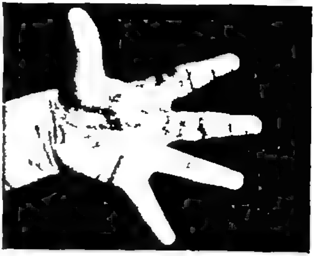


FIG. 167 Case R. B., aged 3 (*Left*) Flexion contracture from brush burn by electric wringer (*Right*) Correction by excision of cicatrix and replacement by full-thickness skin from abdomen.

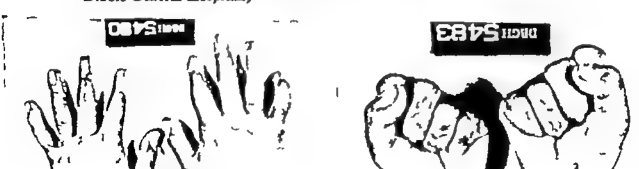
A

FIG. 168. Keloids from burn replaced in stages by thick skin grafts. All borders of graft except on left little finger are midlateral or transverse thus avoiding keloid formation. (A) Right preoperative. (Courtesy of W B Macomber Lt. Col., M.C., Dibble General Hospital.)

B

FIG. 168 Keloids from burn replaced in stages by thick skin grafts (*Continued*) (B *top*) Right, grafted. Left, preoperative. (C and D, *bottom*) Postoperative. (Courtesy of W B Macomber Lt. Col. M C., Dibble General Hospital.)

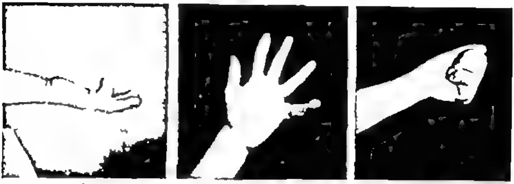
C



D

plaster for inspection of the condition of the finger tips.

Partial thickness Grafts (Split Grafts) In questionable beds, grafts of partial thickness are more apt to take than with grafts, infection is terminated and we avoid the too luxuriant growth of granulations which later leads to contracture. At a later date, this poor Thiersch graft can be excised and good skin laid in its place.



A B C

FIG. 169 (A) Contracture from burn in a child.
(B and C) Cicatrix replaced by two-thirds thickness skin graft.

are those of full thickness The more questionable the vascularity and asepsis of the bed, the thinner should be the graft. Thicker split grafts give a much better quality of skin than do thin ones, because they contain more skin structures A three quarter thickness graft from thin skin yields better coverage than the same thickness from thick skin like in the back Thiersch grafts do not furnish all the necessary structures to grow into good skin, as they include very little of hair follicles, sweat, sebaceous glands, and fat. To obtain the best quality of skin we should select the greatest thickness of skin which will survive in that area. Thin skin or Thiersch graft will grow even on granulating surface, where thicker grafts usually fail Thiersch grafts heal in ten days, but the thicker grafts require three weeks or more The thinner the graft, the more will be the contracture. Full thickness grafts contract very little and the contraction takes place in the layer between the graft and the host Some hairs are carried with them. Thin or Thiersch grafts are useful to close in quickly raw granulating areas, immediate wounds, or places from which skin flaps have been swung By closing in raw areas It will be found that by that time the Thiersch will have shrunken to a very small area, having drawn the good surrounding skin toward itself To graft when luxuriant granulations are present, under the ischemia of a tourniquet, the granulations are scraped off with a handle of a scalpel. The graft and pressure dressing are completed before the tourniquet is removed By removing all granulation tissue the grafted area will be found to be soft, pliable and free from cicatrix. It is the granulating area that turns to cicatrix Evulsed skin may be glued to the dermatome, split as desired, and replaced.

Split grafts at first scale excessively and appear very rough, but later they become softer and more like normal skin and their area becomes much reduced from shrinkage. Thick or full thickness grafts seem to acquire, even after a year, some subcutaneous tissue.

In repairing contractures of the hand by split or full thickness grafts, first all surface scar and underlying cicatrix should be excised to good skin borders all around. The skin should then be undermined, it will be found to be adherent at the periphery of the defect and as it is undermined

widely it will retract. Enough deep cicatrix should be excised so that the hand or wrist can be placed into the position opposite to the deformity, at which it should be fixed by splinting Care should be taken not to overstretch nerves Tendons should be freed enough each way to allow the joints to bend sufficiently Tendons, bones, and joints should then be covered by drawing over them and fastening by No 000 catgut thin layers of vascular tissue. The split graft is then applied and sutured in place

Earl C. Padgett has developed the best method to date of obtaining uniform partial thickness skin grafts of any desired thickness His calibrated dermatome allows these to be cut from arms, legs, chest, back, or abdomen in one piece as large as 4½ x 8 inches. The grafts are so uniform that a new crop can be taken in one month from the same donor site Recently, we covered in three crops the entire area of both legs and buttocks in a man The skin is glued to a drum with rubber cement. As the drum is rolled off, raising up the skin, an oscillating knife set for the desired thickness automatically cuts the graft.

Padgett gives the following figures

Thickness in inches

008 – 010	Thiersch
012 – 020	Superficial intermediary ¼ to ⅓ of full thickness
022 – 030	Deep intermediary 75 to 95 per cent thickness
032 – 045	Full thickness 100 per cent

If too deep may take all skin elements.

010 – 012	Not over this in baby
014 – 016	This may be too deep for child of 6
016 – 018	Not over this in child of 12 to 14
018 – 020	May be too deep in woman with abdomen stretched by pregnancy or on inner side of thigh or arm

Grafts that will take over granulation tissue are not over .014 inch in thickness, and 012 inch is usually used On a clean bed any thickness can be used Twenty two thousandths to 028 inch gives better appearance and less contracture. Sixteen thousandths to 020 inch is more certain to

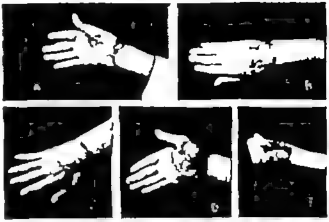


FIG. 170 Case J L L.
(A B) From gasoline burn hand is bound by scar
(C D E) Cicatrix has been excised and replaced by good pliable skin of two-thirds thickness.

take. It is possible with a dermatome to remove the full thickness of skin, including all skin elements Therefore, the above figures should be kept in mind. If full thickness be desired, the donor site may be covered over at once by a thin split graft. In grafting over granulations, penicillin, 5,000 units per cc., in the dressings, will help

Placing Free Grafts. Thin skin grafts have less immediate shrinkage and can be laid out in pieces raw side up on a wet sheet of rubber, like a mosaic, with their edges overlapping The whole is laid on the area to be grafted, pressed with a pad of gauze, and the rubber peeled off

Split grafts contract, so they should be sutured in place Poth advises first laying the mosaic of skin pieces face down on a smooth hard surface They stay spread from adherence A layer of gauze is placed over this and painted with collodion When dry it can be picked up, laid on the site, and attached to the surrounding skin by collodion to the gauze edges.

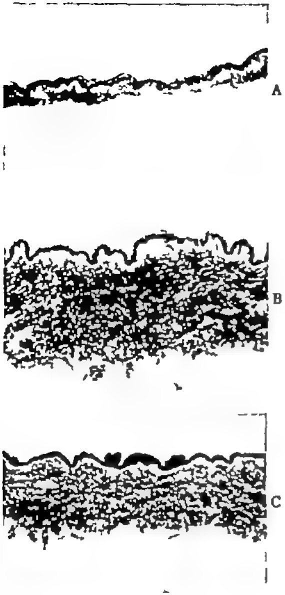


FIG. 171 Skin grafts of varied thickness.
(A) *.010 inch—.25 mm. From adult.*
(B) .018 inch—.46 mm. From abdomen of adult male.
(C) .030 inch—.76 mm. From thigh of 65-year-old male.
(From Padgett's Skin Grafting Courtesy Charles C Thomas, Publisher)

Padgett Dermatome Keep glue thin like syrup in tall jar kept covered to prevent thickening from evaporation. Keep brush in ether Drum must be dry and not hot Skin should be dry and cleansed with alcohol and ether instead of merthiolate After two quick brushings, let the glue dry well Folded gauze is better than a brush Hold drum in place for several minutes before starting Cut slowly to roll gradually, taking plenty of time. Do not rock. Short, even strokes prevent detachment *from skin If cutting is too shallow* at one end, advance that edge and vice versa. In cutting several drumfuls, each may be left attached to the skin and replaced over the bleeding bed. Sulfanilamide powder sprinkled on the outside checks the stickiness of the rubber cement. This is better than placing the grafts in salt solution as *it does not wash off the* plasma glue. Bobbinet, nylon or oiled silk may be attached to the drum by rubber cement before cutting (Jenney and Berkon) to facilitate placing the grafts. Zintel resplit the skin graft to obtain three drumfuls from one With the dermatome a graft may be readily cut from avulsed or detached skin by merely *gluing it to the drum.*

Buried Skin Grafts These are useful to establish the depth of an interdigital cleft by tunneling through the web between the fingers, or similarly to relieve a line flexion contracture by tunneling across beneath it and placing an epithelial graft wrapped around a ribbon-shaped stent. *Later, when the contracture is cut through,* the gap between its ends will be found lined with epithelium. A stent of wax of any shape covered with split graft can be buried where some deep cleft is to be established, such as in phalangization. A lead strip does not interfere with the take.

Skin Grafting in Office. This can *readily* be done in closing over recently traumatized areas, finger amputation stumps, or any place where the area is small *The skin is shaved, cleansed, and* painted with merthiolate solution. This on the donor area, is beneficial to the graft, but chemicals should not be applied to the area to be grafted.

Anesthesia is furnished by the ethyl chloride spray, and cutting the skin just as the area is thawing out is painless. It will *be found easier to cut* a skin graft when partially frozen, and the take will not be in the least hampered.

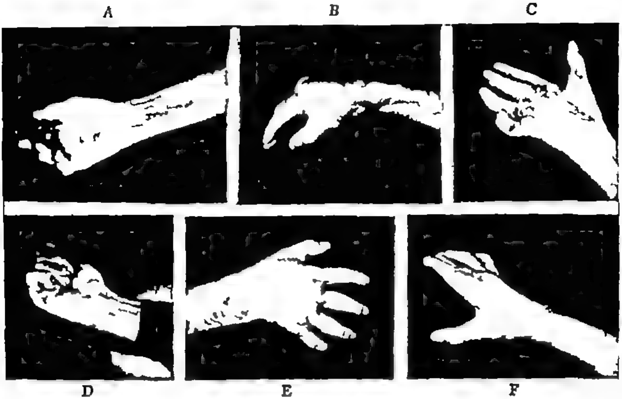


Fig. 172 Case G H P Keloid contracture from burn by molten lead. Digits are webbed and so bound together that there is very little motion as shown in (A) and (B) Cicatrix-covered fingers and palm.

After excising the webs, a strip of dorsal skin was laid across each cleft. Much cicatricial skin was removed from fingers and palm excising the latter in two lines transversely and longitudinally breaking the lines of tension and allowing the hand to unfold

After placing the hand on a spreading metal splint, the denudations of palm fingers and all clefts were filled in by free grafts 020 inch in thickness.

Liberation from cicatrix allowed return of nutrition and good motion of the hands (C, D E, F) The skin is durable and free from webs.

For office use and where only small grafts are needed the Marble skin graft razor is most handy It consists of merely a holder, into which is attached the long Duplex safety razor blade For all larger skin grafts we prefer the Padgett derma tome.

Dressings for Skin Grafts. Donor areas should be dressed with the smooth surface of fine mesh gauze impregnated with petrolatum or zinc oxide ointment, or preferably with rayon of too fine a mesh to admit granulations All clots should be washed away and pressure applied in the dressings Whenever such a thick graft is taken that fat globules show in the donor site a thin graft should be applied to the donor site to replace the thick one. Otherwise, healing will be greatly prolonged. If the area becomes infected, it can be cleared in a few days by boric acid compressing, followed by Bland ointment or air dressing Even late it may be advisable to cover a donor site with a thin graft The skin graft itself, unless of the thin Thiersch variety, is fastened in place by stitching and then held against its bed by wrapping spirally about the finger or limb a strip of wide meshed paraffine gauze This may be fastened to the skin at each end by sterile adhesive plaster or a stitch. Over this a layer of rayon is placed Some prefer first a few layers of 3 per cent xeroform ointment gauze Poth recommends gauze wrung out in pure glycerine Even pressure is applied outside the gauze The paraffine gauze allows changes of dressings and prevents the graft from slithering Even pressure prevents formation of hematoma which might separate the graft from the bed, and

FIG. 173A. Keloid formation in donor areas occurs in some individuals when the cut is deep into the derma.

insures freedom from edema and close approximation between these structures so they will grow quickly together. If bleeding cannot be stopped, the limb should be rendered and kept ischemic until the graft is placed and a pressure dressing applied. The smallest blood clot will spoil the overlying graft. All should be washed out by squirting salt solution with a syringe beneath the skin graft just as the pressure is being applied. To furnish the pressure the following may be used: soft sponge or sheet sponge rubber (elephant's ear), cotton waste, fluff gauze, wax stent, or sea sponge. If a wax stent is molded to the surface it may be fastened there by sutures placed through the skin and directly over the stent or by adhesive plaster. Sea sponge should be fine-grained. If wet with water it soon dries hard and irregular, but if wet with 25 per cent glycerine in salt solution it retains its elasticity.

Skin grafts always heal better if an immovable stent of some of the above materials is tied over the area. Skin sutures are left long and are tied to each other over the stent. A pressure dressing is then applied over all.

A method insuring excellent takes is to combine immobility, pressure, and wetness. The latter is furnished by instilling solution through rubber tubes embedded in the dressings.

This pressure is maintained for ten days without change of dressing. Absolute immobilization by splint or preferably plaster of Paris is necessary for free grafts, especially for the thick ones. When tissues are edematous, healing is greatly benefited by application of a pressure bandage. This is particularly beneficial when luxuriant granulation tissue is being skin-grafted.

For radiation burns see Chapter 12, "Injuries of the Hand."

CONTRACTURES FROM BURNS

Scars left from burns overheal in subcutaneous tissue and contract, leaving keloid formation and excessive contracture deformities. Burns of the hand and arm occur in certain typical patterns. The child puts his hand on the hot stove or catches it in a hot mangle, resulting in flexion contracture with strong keloids of the palm and fingers. Burns from inflammable liquid frequently involve the dorsum of the hand and fingers and also much of the circumference of the wrist. The thick, broad, contracting keloids that form limit flexion of the fingers and motion of the wrist. The matrices are distorted and drawn out proximally from the fingernails. After mild burns the fingers may flex with some strain, but in doing so the tight skin over the knuckles blanches. There is the complaint of aching, a stiff feeling, limitation of motion, and weakness of grip. A pattern of keloid frequently encountered is along the radial aspect of the thumb and thenar eminence, around the heel of the palm and down the volar surface of the little finger, evidently because this region of the hand is more prominent. The thumb and little finger are drawn into flexion and toward the

wrist. War burns make terrible crippling, the usual type showing keloid contraction over the back of the fingers, hand, and fore arm, drawing the hand into a claw with hyperextension of wrist and bases of fingers and flexed, webbed, attenuated fingers The contraction of the dorsum of the hand reverses the metacarpal arch, draws the thumb back so it cannot oppose and hyperextends the proximal finger joints. Dorsal webs extend an inch or more down the fingers, preventing spreading Fingers may be drawn into flexion by volar keloids.

FIG. 173B Marked bony growth deformity in adult due to a neglected skin contracture from a burn when a girl of five. (Courtesy of L. D Howard Lt Col., M.C., Wakeman General Hospital.)

The middle finger joints become strongly flexed when the middle tendinous slip is burned, allowing the flexors to pull unopposed These joints are nearest the flame. When the backs of the joints are roasted ankylosis occurs Even the phalanges or metacarpals may be exposed. When the proximal finger joints are hyperextended, the hand claws as the distal two finger joints draw into flexion from pull of the long flexors When the middle finger joints are held in tight flexion the distal finger joints hyperextend, because of upset muscle balance and tight skin. Palms are burned from burning oil on water handling hot shells or climbing hot ladders. Hands terribly burned become grotesquely distorted with digit and wrist joints drawn into extreme abnormal positions The whole hand may be so encased in cicatrix that the nutrition is very low This should never be allowed to happen. The only preventive is to use radical plastic surgery before the distortions occur Eyes and lids should have the first priority in treatment, and hands next If joints are exposed they should be covered by a pedicle skin flap from the abdomen A hand encased in cicatrix must be covered by new skin, one side being covered at a time, because, for the dorsum the position of flexion and opposition is needed, and for the volar aspects that of extension.

Burned fingers present many problems If there is voluntary extension of the middle joint, a split skin graft will suffice. An excellent finger covering is made from a full thickness graft from above the clavicle or the inner side of the arm

If the middle joint has a fairly good covering, but from loss of the middle tendon slip cannot extend, the two lateral bands, if sutured together across the top, have furnished extension The distal joint, however, will not flex. A new extensor tendon cannot be supplied for the middle joint until the finger is covered by pedicle skin, as it

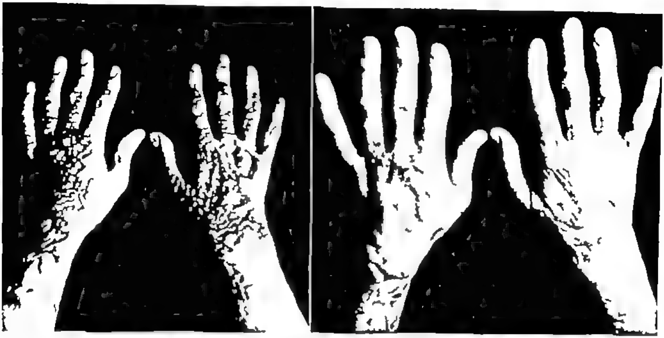


FIG 174 (*Left*) Keloids from burns sustained in airplane crash. (*Right*) Condition six months after excision and replacement with thick free skin grafts using dermatome. (Courtesy of William H Frackelton, Lt. Col., M C., Beaumont General Hospital.)

will not slide under split skin A good joint must be present To restore this tendon see Chapter 10 *With loss of extensor tendon and partial or complete ankylosis of the middle finger joint in strong flexion, the joint should be placed into mild flexion by force or osteotomy under anesthesia and there it should be ankylosed, being fixed by two crossed stainless steel pins.*

When the distal finger joint is hyperextended it should similarly be placed in mild flexion and ankylosed so, using a pin Finger

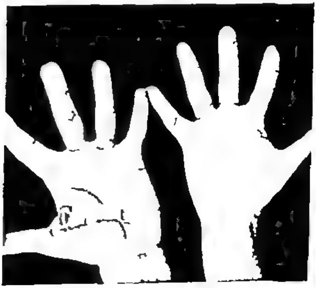


FIG. 175 (*Left*) Contracture in palm from burn. (*Right*) Replaced by thick, free skin graft. Points of graft pass over clefts to prevent webbing (Courtesy of W B Macomber Lt. Col. M.C., Dibble General Hospital.)

nails deformed from burns are difficult to repair Crosscutting the skin dorsally, freeing the skin and grafting the space so left has not helped The whole nail and matrix are best removed and substituted for by a skin graft. The piled up keratosis at the end of and under the nail has been excised the deeper portions of a burn, is so changed that it develops contracting keloids It is this layer that contracts As early as a burn can be cleaned it should be covered by thin temporary grafts or else time will be lost and granulations will pile up, eventually causing contractures by resulting in this

A B C

Fig. 176 Case C. B
(A) Hidebound forearm from contracting keloid as result of burn
(B and C) Strangulation relieved and nutrition restored by making several longitudinal incisions, allowing them to gape and covering the spaces with two wide strips of free skin graft which are visible in photographs.

and traction has been maintained on the nail with the finger over a ball for several months, with some improvement.

To allow the proximal joints to flex, capsulectomy may be necessary This can be done through a skin graft. It can also be accomplished by removing the collateral ligaments from beneath the aponeurotic hood and applying a skin graft at once.

Contracting keloids form especially in places where there is much motion imparting to them intermittent tension and compression, so we find them greatest on the dorsal or palmar surfaces of the hand and worst opposite the joints Often the dorsal aspect of the lower and upper arms, and at times the volar aspect of these, show marked keloid formation from burns This is especially so where the keloid spans the axilla elbow or wrist and is subject to intermittent motion. Often a scar runs across the inner aspect of the elbow and down to the radial border of the thumb and becomes tight on extension of the elbow and supination and extension of the wrist and thumb

Treatment. Tissue that has been partially burned but still recovers, such as in thick layer of cicatrix If such an area is excised down to good tissue and the region is covered over by a free graft of skin there will no longer be the tendency to reform keloid Therefore, the treatment of contractures from burns is excision of the damaged skin and thick subcutaneous cicatrix and substitution of good skin in its place. In burns, the greatest damage is superficial, having been received from without, and it progressively lessens with the depth, so, unlike contractures from infection and injury which are from within, we usually find on excising contractures from burns a good vascular bed underneath, well fitted to receive the free graft. For deep burns, however which extend down to the firmer tissues, tendons ligaments, and bones, pedicle grafts are necessary Where possible the whole keloid is cut away and replaced by as thick a free skin graft as will take the deep intermediary or full thickness yielding the best skin three-quarter thickness for the dorsum but full thickness for the palm

On the dorsum of the fingers, the bed may be so poor that the pedicle graft may be necessary For milder contractures here,

FIG 177 Case C. T (A, *Left*) Preoperative. Result of severe dorsal burn from steam press. Joints are frozen. Skin has been punch grafted.
(B *Center*, and C, *Right*) Dense cicatrix on dorsum of hand and fingers has been replaced by good skin by the tube pedicle method with much improvement in nutrition and movement.

the skin may be cross-cut in several places, allowed to gape, and then covered in by free grafts of intermediary thickness. The fingers should then, of course, be put up in flexion If keloids are present it will be found that under the thin skin of the keloid are thick plaques and bands of cicatricial tissues. These bands cover the dorsum and run down the backs of the fingers and often between them as webs. Often over the extensor tendons is a good areolar layer which will support a free skin graft.

The method of choice when the deep structures are uninvolved is to excise all the burned area of dorsum of hand and fingers, even though it is only a second degree burn, and to cover the denuded area with one large piece of three-quarter thickness skin It is important to excise all plaques of cicatricial tissue and that deepest white cicatricial layer, as this is the cause of the contracture. When it is removed the fingers will flex. If the burn is not deep all veins and subcutaneous fat should be preserved as the skin is dissected off The new skin will then be very pliable and the veins will show through it. The forearm and hand are placed on a splint which is rounded dome-like for the palm so the fingers will be spread and semiflexed, and the dressing is applied with firm rubber sponge pressure. The proximal finger joint long held in extension by cicatrix, may need capsulectomy and at the same time be grafted over by thick split skin graft.

If the skin is cut in two pieces, the juncture should be across the back of the hand instead of longitudinal with it so that it will not thicken to keloid. The area of skin on the dorsum of the spread hand compared with that of the hand in a fist is as 3 4, so plenty of skin should be applied allowing for full flexion of all joints and full opposition of the thumb On the fingers the graft margin should be either zigzagged or midlateral even at the expense of some good skin, as in this line there is no push and pull (Fig 102) It should be noticed that flexion creases in the fingers extend to the midlateral line only Any border of a skin graft that is either anterior or posterior to this midlateral line, unless zigzagged, is prone to thicken to keloid To obtain enough skin in one piece to cover all the dorsum of hand and fingers Converse enlarged his dermatome drum to 6 x 10 inches

Burned skin is removed by using a tourniquet as bleeding is excessive. The tourniquet may be temporarily released for ligation of large vessels, but again pumped up so the field will remain absolutely dry for the skin graft and until after the pressure dressings and also a slab of plaster to immobilize are fastened in place Not until then is the tourniquet removed

Special care is taken in arranging the grafts at the webs Wherever possible a strip of skin from the dorsal or volar surface of the web or side of the finger is laid across the depth of the cleft, or a tunnel graft may be placed prophylactically If a

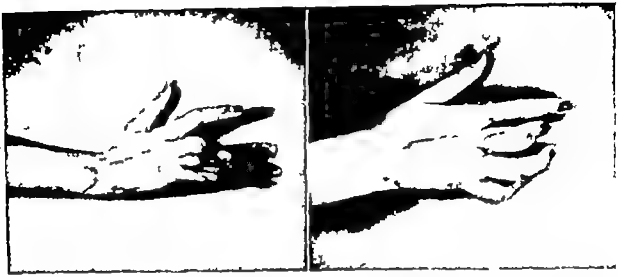


FIG 178 (A) Dorsum of right hand was caught in a steam press and burned deeply (B) Scar was excised and replaced by an interdigitated tubular pedicle skin graft.

graft border loops around a web on the dorsum, it should be deeply zigzagged. It is best to place long tongues of skin graft across a web, prolonging them on both surfaces of the hand to allow for shrinkage. Excellent webs after dorsal burns can be made by raising the skin from the side of a finger, swinging it back to cover half of each web and then skin grafting the dorsum of the hand and fingers When making webs alone after a hand has been skin grafted, it is best to do only the second and fourth clefts first, using long pointed skin grafts held in place by stents, and at a later time doing the third cleft. The advantage of stages is that during the healing the clefts can be kept widely spread. The interdigital clefts are often drawn distalward by contractures from burns to form thick webs, though these can be corrected by tunneling through them and placing a skin graft on a metal strip followed in 10 days by severing of the web and skin grafting the sides of the cleft. Far better clefts can be made by the above-described methods.

When deep structures are involved the skin over the dorsum of all the fingers and hand must be replaced by skin and subcutaneous tissue by a pedicle graft One method is to embed the whole hand under the abdominal skin by the pocket graft method It is advisable first to make all of the incisions in the skin and to raise up the flap and replace it, so that the vascularity will increase in the multiple pedicles. During the three weeks of attachment, sepsis and odor from the palmar skin next the fat will be a necessary evil and will perhaps jeopardize the graft, though the odds are in favor of obtaining a good result. A rubber glove may be used partially to cover the hand while imbedded.

The cleaner methods for covering all fingers at once, either on their volar or dorsal surfaces, are preferable to using a pocket graft One of these is to slit the skin of each finger in the median line either dorsally or down the volar aspect, peel it half off and suture it to that from the next finger, everting the margins so that a one surface mitten is formed A pedicle flap or tube is applied over all transversely or preferably longitudinally (Fig 140) After three weeks the flap is interdigitated for each finger Ample skin should be used and the fingers kept spread for the pedicle skin shrinks and it may be necessary to use some of the base of the pedicle to obtain enough skin for the last finger

To avoid shrinkage it is better to construct the pedicle graft in stages cutting and resewing the interdigitations as the last step before applying them. Either a flap pedicle or a pancake on a tube pedicle is

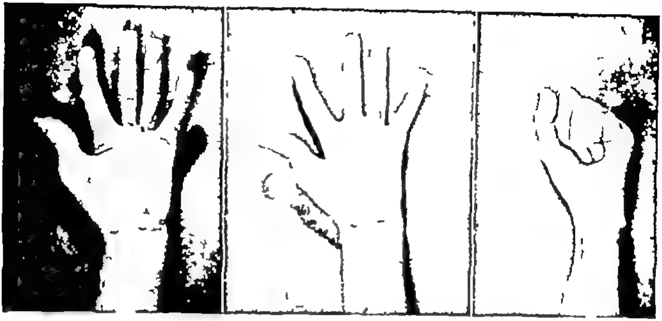


FIG. 179 Case T J B., age 56 Hand was burned by X-rays under fluoroscope.
(A, *Left*) Condition two years later with great complaint of pain.
(B *Center*, and C, *Right*) Burned area was excised widely and deeply and replaced with good skin by the tube pedicle method. Complete relief of pain and good function resulted.

used, placed in such a direction that it will cover the fingers, and, as another step, the dorsum or palm of the hand

When a flexion contracture is excised and replaced by new skin, the limb should, if possible, be put up in splints or plaster in *the position opposite to the original flexion* contracture and maintained so for 3 weeks

Where burns are too extensive to be completely replaced by good skin, the lines of tension in them, where whitening occurs on extension, should be excised or cut across The gap so produced should be covered by good skin, usually by the free graft, but *often by swinging a flap of good skin across* the line or by a pedicle graft. The amount of new skin necessary can be reduced to a minimum by placing it in these strategic places which break the lines of tension. An arm may be hidebound from extensive contracture from burn By making several longitudinal incisions the length of the burn of the limb, thus breaking in about three places the circumferences which are too short, these wounds gape, relieving tension. They are at once covered by split grafts.

Contractures from deep burns in the palm are best replaced by the pedicle graft, though excellent results in the more superficial burn contractures in the palm are obtained by grafts of full thickness.

Hands deeply burned do not flex well. Hindering this flexion is the contracture of *the collateral ligaments and dorsal aponeurosis* of the proximal finger joints, but in addition the transverse metacarpal ligaments have, also, contracted. Normally when it forms a fist, the breadth of the hand increases at the knuckles one-quarter inch. If it cannot do this, flexion is limited Therefore, in deep burns of this region, the *transverse metacarpal ligaments should* be severed

Another complication is contracture of the interosseus muscles, either from involvement in the depth of the burn or due to ischemic contracture from too tight a pressure dressing In either case the muscles should be freed by stripping.

DUPUYTREN'S CONTRACTURE

In 1610 the condition known as Dupuytren's contracture was first described by Plater In 1808 it was referred to in the

lectures of Henry Clive, and in 1818 Sir Astley Cooper wrote that it was due to hypertrophy of the palmar fascia. In 1831, however, Baron Guillaume Dupuytren, after dissecting a hand with this affliction, described the actual pathology

Incidence

Statistics based on over 600 cases, and compiled by various authors—Keane, Anderson, Black, Byford A. Kanavel, J S Davis, A. A Davis, Meyerding, and Bruce Gill—well establish the incidence of this condition

Dupuytren s contracture occurs in perhaps 1 to 2 per cent of the population The older the persons examined, the more frequently the contracture will be found Patients applying for treatment of this ailment range from 11 years to old age A Chinese boy of 17 (personal case) had both hands affected and had never worked. Usually persons seeking treatment are in the late forties or early fifties, and on the average give a history of the trouble having started in the late thirties or early forties, ranging from 7 to 11 years previously It may commence as late as at the age of 60 J S Davis places the age at which contracture begins as follows under 30, 15 per cent, in the thirties, 15 per cent, in the forties, 20 per cent, in the fifties, 21 per cent, in the sixties, 15 per cent, and in the seventies, 1 per cent It occurs in six males to one female.

Authorities, with few exceptions, agree the condition is more prevalent in people who do not use their hands for manual work than in manual workers, in the proportion of 55 to 45 per cent, respectively

Etiology

The etiology of Dupuytren s contracture is still unknown. Many untenable theories have been advanced. There are certain aspects, however, that stand out conspicuously It is prevalent in males and in the aged It is definitely hereditary there being numerous instances of many in a family being afflicted with the condition and of its having cropped out in families in as many as four and seven consecutive generations. The numerous instances of family history are far too common to be coincidental An instance of two brothers with identical bilateral Dupuytren's contracture has been recorded Certain diseases have been more repeatedly associated with Dupuytren's contracture than others, such as gout, arthritis deformans, rheumatic tendency, and diabetes Skoog found 42% in epileptics In 162 hands with Dupuytren's contracture on which I have personally operated, I have been impressed by the fact that people with this condition show a marked tendency toward limitation of motion in their joints on slight provocation Apparently the condition is associated with a diathesis which leads to overgrowth and thickening and contracture of ligamentous tissue

The condition is usually bilateral and may be associated with contracture of ligamentous bands elsewhere. In eight instances, in two of which the Dupuytren's contracture was bilateral, there was also a contracture of the connective-tissue septum between the corpus cavernosum and the corpus spongiosum, known as strabismus of the penis or induratio penis plastica (Peyronie s disease) In nine other cases there was the association of a similar condition in the plantar fascia of the foot, with the maximum contracture in each instance greater in the medial side of the sole than in the outer It was more pronounced over the internal than the external plantar nerve. The latter corresponds to the ulnar nerve in the hand In the foot, the nodules are flatter, the toes are usually not contracted but there may be a tendency towards cavus In one case of Dupuytren's contracture there was a subcutaneous tight, fibrous band running down the front of the left shoulder and arm. In five personal cases of Dupuytren s contracture there was the asso-

FIG. 180 Case J D., aged 43 Dupuytren's contracture. Duration right nine years, left one year Contractures interfere with work. Apostolic hands.

ciated atavistic ape condition of knuckle pads over the middle joints of the fingers

There is often the desire to claim that a Dupuytren's contracture is due to trauma from labor, and early writers held this view Though it is the usual and natural assumption of a patient to ascribe the condition to the effect of a traumatism, as it may be temporarily more conspicuous after trauma, it is clear nevertheless that the cause of the condition is unrelated to trauma Arguments against trauma as a cause are that the condition is idiopathic in origin and associated with other similar conditions and with a general tendency for the ligamentous tissues to undergo contracture. It is usually bilateral, though the right hand receives the most trauma. The fact that it occurs in non workers more frequently than in workers is quite conclusive. There are many injuries of the palm, but these are not followed by Dupuytren's contracture more than would be coincidental

SYMPTOMS

Symptoms from Dupuytren's contracture are not great and often the contracture may be well established without giving any pain or ill feelings. Sometimes the subjective sensations may precede the occurrence of any lump or contracture, or a constant pain in the palm may direct one's attention to a small lump forming in the skin The usual symptoms complained of are a dull ache in the palm, a numb feeling or tingling The patient may complain of cramping, only a few complain of pain The hand may feel stiff in the morning Later when the round cell stage is over, the condition is usually painless At first, there may be only a small nodule in the region of the distal crease in the palm opposite the ring finger Here the skin may be felt to be thickened, and soon a subcutaneous contracting band may be felt in the line of the palmar fascia. The skin at the distal crease rises in a transverse fold and on one or each side of it there may be a crescentic dimpling as the contracting fibrosis draws a funnel like fold of skin inward At first, there may be no actual contracture of the fingers, though if we bend each finger of each hand backward and compare the degree of extension, we will notice *in the affected hand some comparative limitation* of extension

The course of the contracture may be rapid or slow In some instances considerable contracture occurs inside of a year, while in others the course may spread over 20 years. Occasionally there are exacerbations and there may be recessions, some of which seem to be brought about by incidents in the general health such as sicknesses or operation Usually first the ring finger commences to flex in its proximal joint. This may soon be followed by flexion contracture of the proximal joints of either one or both of the adjoining fingers in which case subcutaneous bands of thickened palmar fascia can be felt running to one side or the other of their respective fingers. The middle joint of one or more fingers often shares in the contracture and sometimes eventually flexes to an extreme degree. Rarely does the distal joint contract though I have seen it once and in fact due to the flexion of the middle joint upsetting the muscle balance, it often hyperextends.

As the contracture develops in the palm, the skin over the thickening fascial bands becomes firm with induration. Instead of having the normal resilience or softness from the subcutaneous fat it feels hard, thick, and tight to the thickened palmar fascia Broad plaques of such induration spread out along the course of the thickened fascial bands in the region of the distal crease in the palm They also appear in the volar skin of the proximal and middle segments of the fingers, and frequently there may be such a plaque of skin running between the thenar eminence and the radial end of the distal crease of the palm Here, there is often a separate fascial band contracting parallel to the web between the thumb and index finger Another band may form over the thenar eminence parallel to the long axis of the thumb

With one or several fingers firmly hooked in flexion contracture, there is danger to the patient of being unable to let go when his hand catches hook like on the handle of a street car or other moving object. Many are unable to work because of the contracture. The patient may complain that in washing his face his finger pokes into his eye, or that in shaking hands with people, the finger in their palm leads to embarrassing misinterpretation. When fingers remain strongly flexed, the skin in their folds where the sun never shines becomes foul and in need of cleanliness and a wick of gauze in the creases Similarly, the deep crescentic, funnel-like puckerings of the skin of the palm may become foul.

The ring finger is the one most frequently affected, and the little finger the next. Following this in frequency is the long finger, and the index finger is only occasionally affected. Contracture of the thumb is even more unusual. Tabulations from the above authors in 320 cases give the following relative frequency of involvement of the various digits

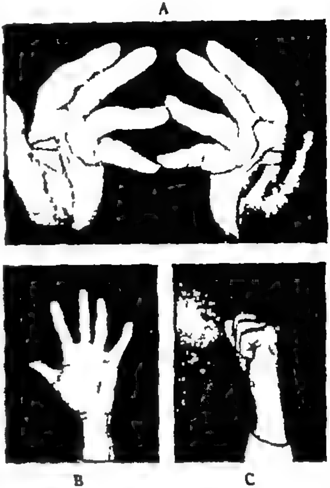


FIG. 181 Case G P
(A) Bilateral Dupuytren's contracture of eight years duration.
(B and C) Condition of right hand a year after excision of the contracting fascia.

Thumb	23
Index	31
Long.	114
Ring.	304
Little	238

J S Davis expresses the relative frequency as follows

Ring	43 per cent
Little	34 per cent
Middle	15 per cent
Index	5 per cent
Thumb	3 per cent

The ring and little fingers are often contracted at the same time and less so the ring and long fingers The contracture usually starts in the distal crease in the palm, though occasionally in the proximal segment of a finger

Dupuytren's contracture occurs bilater

ally in the majority of cases. Case compilations by A. Kanavel, J S Davis and Meyerding place this majority at 48.3 per cent, 53 per cent and 64 per cent, respec

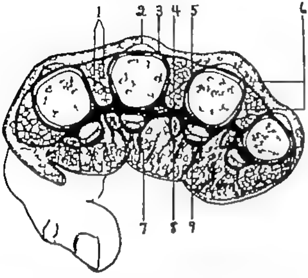


FIG. 182 Cross-section of fresh frozen palm in a plane just proximal to the distal palmar creases.

To show (black) the extensive system of ligamentous septa and fluted arches in the distal half of the palm, which bind firmly the tendons, palmar fascia, and skin to the bones.

Palmar fascia has here fused to the four large arches or pulleys of the flexor tendons, and also to the radial side of each, to the fascia forming the four lesser arches of the lumbrical canals.

(1) Anterior and posterior interosseus muscles
(2) Extensor tendon
(3) Dorsal aponeurosis
(4) Pre-interosseus fascia
(5) Attachment to metacarpal of dorsal aponeurosis and septa from pre-interosseus fascia
(6) Cleavage spaces between metacarpals and surrounding fascia
(7) Fibrous connections between palmar fascia and skin
(8) Lumbrical canal or lesser arch
(9) Tendon pulley or greater arch

tively Their compilations agree in stating that it occurs in the right hand about twice as frequently as in the left in cases which are unilateral.

DIAGNOSIS

Dupuytren s contracture is so typical that there should be no difficulty in its diagnosis, unless it is present in combination with other conditions in the same hand. The characteristic features are loss of fat between the contracting bands and the epidermis, hard nodules and induration in the skin, transverse skin folds and crescentic puckerings, and the arrangement of the contracting cords corresponding with the natural bands of the palmar fascia. There is absence of tendon involvement, the digits can flex completely

Shortened tendons result in flexion of the distal joints which are, if anything, extended in Dupuytren s contracture. Motions of the digits in tendon shortening will be found to be affected by the position of the wrist joint.

In spastic conditions, unlike Dupuytren's contracture, the proximal joints are usually in extension and the distal two joints in flexion. The other hand in Dupuytren's contracture is also usually involved.

PATHOLOGY

Palmar Fascia. The contracting bands in Dupuytren s contracture are merely an exaggeration of the normal palmar fascia and its attachments, a description of which is as follows normally, these structures hold the volar and palmar skin firmly in relation to the skeletal framework, the fibrous bands from the sides of the metacarpals and phalanges to the volar and palmar skin, arching over and encircling alternately first the tendons and then the vessels, nerves, and lumbricales The palmar fascia divides into four slips, one for each finger The deep fascia that envelops the whole hand is attached to all bony prominences and is thickened in the palmar fascia which is part of it. The latter is thus continuous with the thin fascia over the thenar and the hypothenar muscles. It is also fairly thick where it spans between the thenar eminence and the main palmar fascia and base of the index finger In the distal third of the palm the longitudinal septa which pass vertically from the floor

of the palm to the overlying palmar fascia divide the palm into a series of longitudinal tunnels by arching over the structures that pass to the fingers There are eight such arches, the four opposite the metacarpals and covering the adductor muscles of the thumb They also attach to the deep transverse ligament, the capsules of the proximal finger joints, and the annular ligaments over the tendons Superficially, the fibers

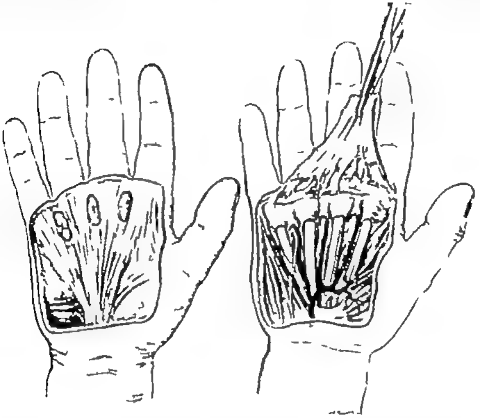


FIG. 183 Palmar fascia and fascial septa in distal part of palm. Eight arches and tunnels are seen with septa between, the four smaller fascial tubes each containing a lumbricalis muscle vessels and nerves In Dupuytren's contracture the palmar fascia and septa undergo fibrous hypertrophy

enclose the flexor tendons, and those smaller ones between opposite the inter spaces each enclose the vessels, nerves, and a lumbricalis muscle. These four smaller channels are known as the lumbrical canals. One of these septa which is so membranous that it is not important, extending between the metacarpal of the long finger and the fascia beneath its tendons, is longer than the others reaching proximally to the distal end of the transverse carpal ligament or slightly farther and dividing the mid palmar and thenar spaces. The above vertical septa fuse with the firm fascia covering the floor of the palm over the interosseus muscles at the sides of the metacarpals run vertically to all parts of the skin covering the palmar fascia, and especially to the folds in the palm Between these fibers are many globules of fat In each finger the palmar fascia divides roughly into three bands, one running broadly down the center and attached to the skin for the length of the finger, and the other two running down each side of the finger to be attached to the ligamentous tissue and periosteum at the sides of the phalanges, annular sheaths, and joint capsules as far distal as to, but not including, the distal joint. Just proximal to the webs of the fingers there is a thin, transverse ribbon of the deeper layer of the palmar fascia with the

fibers spanning across the bases of all of the digits superficial to the nerves and vessels The palmar fascia proximally converges into the tendon of the palmaris longus. In about one-sixth of the cases of Dupuytren's contracture, strangely enough, *this tendon may be absent.*

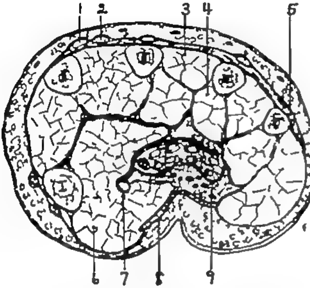


FIG. 184 Cross-section of fresh frozen hand in a plane through the center of the metacarpals. Here the hand is largely of muscles, the passageway for the flexor tendons and median nerve being small.
(1) Extensor communis digitorum
(2) Extensor indicis proprius
(3) *Posterior interosseus muscle*
(4) Anterior interosseus muscle
(5) Extensor minimi digiti proprius
(6) Thenar muscles
(7) Radial bursa and flexor pollicis longus
(8) Palmar fascia
(9) Ulnar bursa. Between palmar fascia and ulnar bursa are volar digital nerves and vessels

Pathologic Involvement. In Dupuytren's contracture a part or all of this *palmar fascia and its vertical attachments* undergoes continuous thickening and contracture by proliferation of cicatricial tissue, drawing the proximal and middle joints of the fingers into flexion contracture, puckering in the skin of the palm—especially at the creases—to crescentic, funnel like depressions and binding down the whole structure tightly to the sides of the metacarpals and the adjoining ligamentous tissue. The greatest proliferation is usually at the level of the distal crease in the palm, and is attached to the proximal margin and sides of the vaginal ligaments encircling the flexor tendons. The short fibers from the palmar fascia to the *skin so proliferate and* contract that they squeeze out all subcutaneous fat and even the sweat and sebaceous glands and the blood and lymph vessels, so that a thick plaque of tissue forms continuous between the epidermis and palmar fascia. Microscopic cross-section of the skin in Dupuytren's contracture shows great thickening of the cornified layer, thinning, and flattening of the stratum mucosum and obliteration of the papillae of the corium, which normally extend up deep into the epidermis. The papillae have been pulled downward and obliquely by the contracting fibers Descending deeper we see in the early stage some round cell infiltration of the connective tissue suggested inflammation but later nothing but dense cicatricial tissue which has squeezed out all the fat and deeper structures of the skin This tissue is somewhat more cellular and vascular in the early cases, when it has even been mistaken for fibrosarcoma, but eventually becomes thick, dense cicatrix. All is fibroblastic and closely resembles a fibroma Some is packed with nuclei and in others there is largely intercellular matrix in longitudinal arrangement. From the irritation of repeated attempts to extend the fingers these contracting bands which are like deep keloids even microscopically, thicken and contract the more. In places such as the distal crease in the palm, an area just proximal to the web of the thumb or the volar skin of the proximal segments of the fingers, the cicatrix under the skin may thicken to a solid, broad plaque strangling out all fat and normal structures and covered by a mere thin layer of epidermis When a digit remains in flexion contracture all of the tissues in its volar aspect—skin, nerves, joint capsules, etc.—become secondarily con

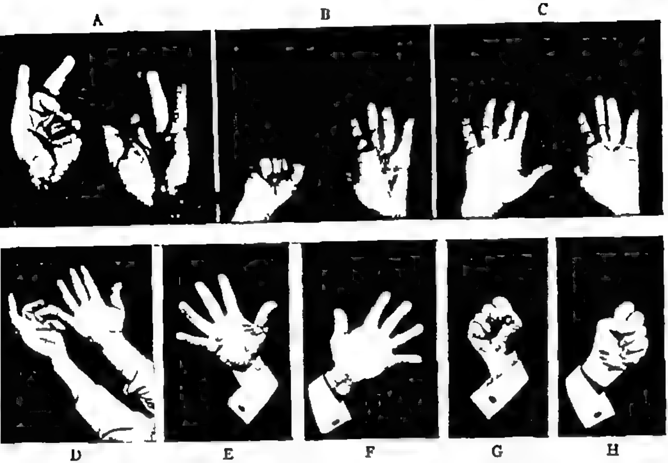


FIG. 185 Case A. M aged 58.
(A) Dupuytren's contracture May 2 1927 Also present similar contracture as strabismus of penis.
(B and C) Same December 8 1927 Right hand has been operated upon.
(D) Same case. Left hand has progressed.
(E F G and H) Same case February 18 1936 both hands postoperatively

tracted, so that even after the palmar fascia and bands are excised the finger cannot be completely straightened.

TREATMENT

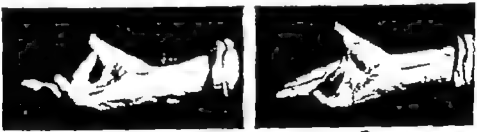
Dupuytren treated the contracture named after him by multiple transverse incisions through skin and fascial bands Later the severance of these bands was done subcutaneously but, though there was temporary relief, the contractures would reappear Many other methods were tried unsuccessfully Irradiation resulted in temporary softening of the bands, but recurrence followed. Radical excision of all of the thickened fascia is the method of choice Unless this is done correctly the results will be bad Many patients have evidently already been warned of this, which shows that there have been many failures. Poor results have followed incisions made longitudinally in the lines of the contracting bands, for these are quickly followed by recurrence of contracture. Often not all the fascia has been removed, or could not be from failure to use a tourniquet, or after operation skin has sloughed followed by infection Nerves may have been cut, resulting in anesthesia in the fingers The object of radical operation is to remove en bloc all of the cicatricial contracting tissue, including the palmar fascia, its connecting fibers to the skin, the septa to the sides of the metacarpals and transverse metacarpal ligament, and the lateral and median bands running down the fingers.

Great difficulty is encountered in achieving healing per primam The skin left after excision of the fascial bands is merely thin epidermis without vascularity and it

A B

FIG 186 Case J A. B Effect of preliminary subcutaneous preoperative tenotomy on Dupuytren s contracture.
(A) Before tenotomy
(B) After tenotomy of main band. It gives skin and nerves an opportunity to lengthen for 10 days before operation.

is in the part of the hand where there is the greatest motion. Unless careful precautions are taken this skin will slough, leaving necrotic and eventually raw areas which greatly delay convalescence and leave contracting scars where least desired. Splinting is necessary to allow these areas to heal, and the longer the hand is splinted and the wounds in it allowed to remain open, the greater will be the stiffening of the joints and other tissues In such a case *it may take a year before the fingers will* completely flex, for patients with Dupuytren s contracture are prone to stiffening of *the joints and contracting of the ligamentous tissues.*



A B

FIG. 187 Case A. E., aged 69
(A and B) Dupuytren s contracture, five years duration. Interferes with washing face, shaking hands and letting go of street cars. This type needs a preoperative tenotomy *gradually to lengthen the skin.*

Operation should be done at an early stage before the skin over the contracture has lost its vitality, and before the skin, nerves and joint capsules have secondarily become too short to allow the fingers to be extended after the contracted fascia has been removed.

Operation is not indicated until the skin of the palm is becoming fibrous or i digital contracture has commenced W the hands can no longer imitate the posi of prayer, *operation is indicated.*

Preliminary subcutaneous tenotomy the main fascial bands under local a thesia with a cataract knife is advisabl cases showing marked contracture. splint, or a rubber sponge bandaged the palm, is then applied to lengthen s nerves, and joint capsules gradually, the radical operation is done in 10 to days, or before recontracture occurs. tenotomy incisions are made at the site the contemplated operative incision, care is used not to interfere with areas be utilized as skin flaps or to sever ner

Operative Technic. Ischemia fr *tourniquet by blood pressure band is ess* tial for accurate dissection Block an thesia is generally used, because the wh operation can be finished in an hour dorsal splint should be boiled up with *instruments. The incision should para* the distal crease in the palm, and tow the ulnar border should turn bluntly pr *imally along the course of the flexor t* dons of the little finger to the base of palm. Through this L-shaped incision th broad flap of skin is dissected *up from t* palmar fascia, removing from it all fibe of this fascia. The skin throughout the i cision is widely undermined in the pla between the deep fascia and the superfic fat. In the worst places, where there is i more fat, the skin is shaved very thin

careful excision en bloc is made, taking all the thickened fascia Commencing at one side of the hand and at the base of the palm one dissects cleanly as one goes, removing every vestige of deep fascia. Dissection may be done with sharp, double-pointed scissors curved on the flat, or with knife, or at times with a probe. The palmar fascia where it converges to the tendon of the palmaris longus is cut across, the cut end is grasped with a hemostat, and as the dissection proceeds in an orderly manner across to the other side of the palm and on distally to the bases of the fingers this fascia is held taut and cut free until it is holding by only the bands running on down the fingers As each volar digital nerve and artery is reached, the fascial septum running between them and the flexor tendons is trimmed off very deep in the hand where it joins the ligamentous tissue at the side of the metacarpal and the transverse and vaginal ligaments. Care is used not to open any tendon sheath or to sever the motor thenar nerve or any of the tiny nerves to the lumbricalis muscles, or, of course, the volar digital nerves. Always locate the nerves before cutting freely Eight septa in all, extending from the palmar fascia through ligamentous tissue to the skeletal framework, are excised. The septa arch first over the tendons and then over the nerves, vessels, and a lumbricalis muscle to each cleft, and alternately so across the palm, and thicken superficially into the palmar fascia. The proximal ends of the vaginal ligaments are trimmed cleanly and preserved The thickened fascia over the lumbricalis muscles and the hypothenar and thenar eminences is also trimmed away By blunt and sharp dissection the fascial bands are traced down from the palm into the bases of the fingers

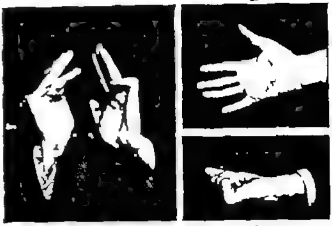


FIG. 188. Case T E S., aged 40 Dupuytren's contracture started bilaterally eight years ago.

(A) Also the plantar fascia of each foot is involved.

(B and C) Result after excising thickened fascia through an L-shaped incision in the palm and lateral ones in the long ring and little fingers.

Each finger affected is then opened through a midlateral incision and sometimes through such an incision on each side. First, the volar digital nerves and vessels are located and so protected, then, all of the thickened fascial bands are dissected out completely and excised. These bands are either outside or inside the volar digital nerve, or they may completely surround the nerve in a fibrous mass. They may attach to the side of the proximal or middle phalanges, vaginal sheaths, or the ligamentous tissue at the side of the joint capsule. Often there is a deep volar lateral band spanning the middle finger joint that, together with the anterior part of the joint capsule, must be excised before the joint will extend The central band is often densely adherent to the skin along the volar aspect of the proximal and sometimes the middle finger segment. This skin may have to be shaved very thin Unless all volar digital vessels are preserved gangrene of a finger may result.

A useful method in a strongly contracted finger is to use the Z-plasty as suggested by McIndoe The first cut is medial longitudinal, and the other two cuts are from each end of this in opposite diagonals. An excellent exposure is provided. Whenever there is not sufficient skin split grafts may be added.

After every vestige of thickened fascia has been removed the effect of secondarily contracted tissue will be seen. The finger

should not be extended farther than the skin and nerves will easily tolerate. In a sharply contracted middle finger joint it may be necessary to strip or excise the void of vascularity should be excised This is especially true of the area in the region of the distal crease in the palm opposite the ring finger The volar skin over the prox

FIG. 189 Case J A. aged 61
(A) Bilateral Dupuytren s contracture starting three years ago
(B and C) Same postoperatively

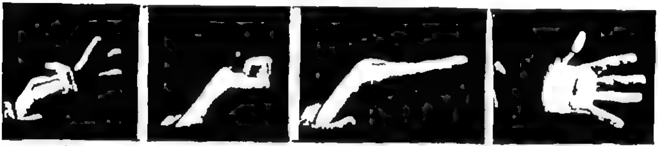


FIG 190. Case H. M., aged 30. Dupuytren s contracture bilateral right, started two years ago and now interferes with work left, started seven years ago.
(A) Left hand preoperatively
(B C and D) Left hand postoperatively

anterior and anterolateral parts of the capsule of the joint before the latter will extend Too much extension at this time may result in dislocation, which may later require amputation at the middle joint.

If a finger is too badly contracted to save it may be amputated but first it should be boned and all possible of its good skin used to cover in any area in the palm where the skin, because of too poor quality, is excised. If it is the little finger, its metacarpal should be removed obliquely at its base, reattaching the hypothenar muscles to the ring finger and gaining slack by narrowing the hand Our aim is to acquire primary healing so as to avoid stiffening of joints and contracture from scar which follow prolonged convalescence. Therefore, skin which has been shaved too thin and is de-

imal segment of a finger, even if shaved very thin, will often live as it is practically a Wolfe or full thickness skin graft. In the palm and sometimes also in the fingers, it is better to cut away questionable skin and to replace it with a thick intermediary skin graft by the Padgett dermatome, or by a full thickness graft from the abdomen. Where such grafts are used, absolute immobility by means of a dorsal splint and a pressure dressing are compulsory Should the skin in an extreme case of Dupuytren's contracture be too badly involved, one should apply over the defect abdominal skin by the direct pedicle flap method.

On completing the dissection of the hand the tourniquet is removed while the wounds are pressed steadily with gauze for five minutes to allow clotting The remaining

bleeders are tied with No 000 or 00000 catgut. At this stage the superficial palmar arch is seen to move with each heartbeat, and all of the nerves and other structures of the hand free from fascial covering show like an anatomic illustration The incisions are closed with fine stainless steel wire, leaving in place about three small rubber tubes for drainage. Without this precau tion and a rubber sponge pressure dressing, hematoma generally follows such dissec tions and greatly detracts from the result. No attempt is made at this time to straighten the fingers completely, for if we do the skin will blanch and be given an additional strain in healing Now that the contracted fascia is out, the fingers will readily straighten out gradually after the wounds have healed. A dorsal splint is applied which will immobilize the proximal finger joints, but will allow free movement in the middle and distal finger joints so as to prevent stiffening and to keep the tendons gliding Splinting for the first two weeks is necessary to immobilize the distal crease in the palm so that it will heal per primam the splint of choice being that shown in Fig 79B, C, D

Postoperative Treatment. On the fol lowing day the drains are removed Steady, firm pressure by the rubber sponge is main tained throughout the first week and if skin grafts have been used, for the first two weeks. Too early motion interferes with healing, in that the most mobile part of the palm—the distal crease—needs im mobility to heal. Too prolonged splinting stiffens the fingers. The proper timing of immobilization and exercise insures pri mary healing and limber joints Motion in the middle and distal finger joints should be allowed from the beginning and encour aged after the first week, to prevent adhesions of the tendons in the palm

In spite of the above precautions some necrosis of the skin flap may occur at the distal crease in the palm, which will demand continuation of immobilization to allow healing For the final healing a piece of a tongue blade can be fastened by ad hesive across the distal crease of the palm, or better, a small flat metal or plastic splint can be shaped to the dorsum of the hand with a gutter like extension extending over the proximal segment of the most involved finger Adhesive plaster holds it in place so the distal crease will not move and still the other fingers may be exercised

It must be remembered that persons with Dupuytren's contracture are inclined to stiffen in the joints and contract in the liga ments, so that the ability fully to flex the fingers may be slow in returning If heal ing is primary and immobilization short, flexion may be complete in a month If healing be delayed, and immobilization cor respondingly long, it may take a year be fore complete flexion of the fingers is attained

Usually, from the above procedure there will be a complete and permanent cure Some patients will return later showing more contracture in some of the parts where fascia had not been excised, as not involved at the time such as in some fin gers or near the thenar eminence and sometimes also in a finger where the contracture was too extensive for complete removal Apparently Dupuytren's contracture spreads from the fascia in situ, and if this is com pletely removed it will not recur at that site

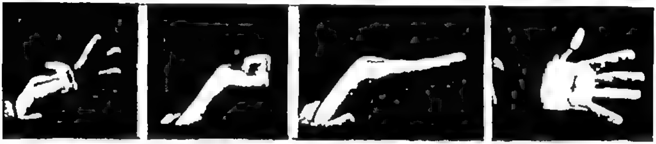
VOLKMANN'S ISCHEMIC CONTRACTURE

In 1884 Leser reported four cases of this entity Richard von Volkmann of Halle described the condition in 1869 1872, and 1881, referring to it as a rapid post trau matic muscle contraction reaching its cli max in a few weeks. In 1914, J B Murphy published such a comprehensive résumé of the subject that advances since have not been great He advised as treatment slit ting the deep fascia in front of the elbow within the first 36 hours after injury The

should not be extended farther than the skin and nerves will easily tolerate. In a sharply contracted middle finger joint it may be necessary to strip or excise the

A B C

FIG. 189 Case J A. aged 61
(A) Bilateral Dupuytren s contracture, starting three years ago
(B and C) Same postoperatively



A B C D

FIG. 190. Case H. M. aged 30 Dupuytren s contracture bilateral right, started two years *ago and now interferes with work left, started seven years ago.*
(A) Left hand preoperatively
(B C and D) Left hand postoperatively

anterior and anterolateral parts of the capsule of the joint before the latter will extend. Too much extension at this time may result in dislocation, which may later require amputation at the middle joint

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It must be remembered that persons with Dupuytren s contracture are inclined to stiffen in the joints and contract in the ligaments, so that the ability fully to flex the fingers may be slow in returning If healing is primary and immobilization short, flexion may be complete in a month If healing be delayed, and immobilization correspondingly long, it may take a year before complete flexion of the fingers is attained

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some cases, a tight hematoma also was present.

Veins are always engorged Tight skin across the front of the swollen elbow occludes the superficial veins and fold of the bicipital fascia across the elbow either by direct pressure over the vessels due to swelling, or by backward displacement of them in case of supracondylar fracture so its sharp edge occludes the vessels against the upper fragment, causing engorgement of the deep set of veins in the forearm. It is immaterial if below the elbow the deep and superficial veins communicate for all veins are occluded as they converge and pass under the tight skin of the antecubital space and in most cases the tight cast or other constricting dressings there. When an elbow is flexed even when not swollen, the yield of the skin across its front is very slight.

The brachial artery in the antecubital space is often found to be ruptured, thrombosed or drawn out and reduced to a string Some have claimed the narrowing to be due to a spasm effect from direct trauma, and in one case the vessel was seen to be normal again six months later Often enough the artery, vein and median nerve have been found actually torn in two by the projecting sharp edge of the upper humeral fragment, and in other cases merely squeezed between the tight fascia and swollen forearm or hooked backward by the fascial edge. Embolism has been found at the forks of the artery, resulting in Volkmann's contracture in 48 hours.

FIG. 192 Post traumatic circulatory disturbance from trauma, plus constriction. Hand and forearm were squeezed by two flat metal pieces. No bone was fractured A nonpadded cast was on for 22 hours. Great swelling and pain continued, with gangrene of the end of all the digits and long time of healing. Lower several inches of flexor muscles became fibrous and contracted. Only a trace of motion. Not a true Volkmann's contracture.

The whole contents of the anterior closed fascial space are found to be tensely swollen with edema and are ischemic, the main part of the blood present being in the form of either extravasation or hematoma.

The muscles, at first greatly swollen, show central necrosis of homogeneous appearance with few nuclei, but in their periphery there is inflammatory reaction with round-cell infiltration and later fibrosis The surrounding connective tissue and intermuscular septa show similar reactive infiltration followed by fibrosis. Eventually the necrotic muscle is absorbed, replaced by scar, and the whole mass undergoes contracture. Here and there patches of active muscle tissue remain. The flexor digitorum profundus and sublimis and the *flexor pollicis longus* are usually more destroyed than are the pronator teres and flexor carpi, perhaps because the former are against the unyielding bones and interos-

seous membrane Nerves in mild cases show destruction of axones and myelin sheaths, and, in more severe cases, they show increase of fibrosis in the endoneurium There may be replacement of nerve bundles, ranging to total necrosis of the nerve Pressure sores and sloughs are common accompaniments due to the swelling in casts Fibrous tissue encircles, contracts and impoverishes lymphatics, blood vessels and nerves resulting in poor nutrition throughout the anterior part of the forearm and hand

Mechanism

There has been much experimentation and discussion as to the etiologic rôle of this unique entity whether of arterial occlusion complete or partial venous obstruction, a combination of both of these and the additional factor of pressure from extrinsic or intrinsic causes Still another factor may be vasomotor spasm

Arterial occlusion alone causes gangrene, not of the contents of a fascial space alone but of the extremity, commencing in the digits. Arterial occlusion by emboli, gun shot wounds etc., has resulted in muscle contractures in limbs as part of the picture Brooks found that a tourniquet left on for five to 24 hours or a permanent stoppage of an artery caused temporary paralysis or gangrene, but not a true Volkmann s contracture. Skin fared even worse than did muscle.

Ligation of all arteries to the rectus femoris gave atrophy only, but of all veins gave contracture resembling that of Volkmann s.

Occlusion of the artery entering the fascial space in the forearm does not rob the space contents of all its blood. From anastomoses about the elbow a backflow can enter the fascial space through the posterior interosseous artery Insufficient but not total loss of arterial supply causes the tissues to swell with edema and necrotizes first in the muscles.

Venous obstruction promptly brings about engorgement with blood Soon capillary resistance is overcome at 60 mm of mercury, and at 100 mm petechiae and extravasation of blood commence, accompanied by edema In a closed space even

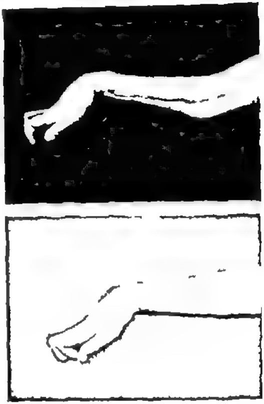

Fig. 193 (*Top*) Case J S Volkmann s ischemic contracture following unreduced supracondylar fracture Decompression was done, but too late. All flexors sloughed.
(*Bottom*) Case E E. Volkmann s ischemic contracture from tight cast for Colles fracture.

arterial inflow is reduced regulated only by the amount of outflow Brooks found that venous occlusion caused hemorrhage, edema, and degeneration of muscle fibers, resulting in acute inflammation progressing to fibrous contracture He described more inflammation than degeneration, but did not test it in a closed space He concluded that venous obstruction is the primary cause of the condition.

Jepson bandaged for varying lengths of time above the knee and ligated arteries and veins obtaining contracture typical of Volkmann s Early drainage helped to prevent it. He concluded as the cause venous

FIG. 194 Age 46 A year ago following a Colles fracture a cast was applied. It was split in four days, and a new cast was applied. The patient (age 41) had very little sleep for a month, because of pain, after which the cast was removed. The fingers were drawn in then, but increasingly more for a year Sensation was lessened in glove area.

pressure, impaired circulation, plus pressure. Ligation of femoral artery and vein and deep femoral vein caused the contracture.

A closed fascial space under pressure in addition to partial venous and arterial obstruction furnishes the requirement to result in Volkmann's contracture. The circulation is slowed and congested, not stopped. Usually the pulse is faint or temporarily impalpable at the wrist. There is still some, though insufficient, arterial inflow and venous outflow This causes edematous swelling which gives the added factor of pressure in the space keeping out the circulation, thus causing the central necrosis of muscles, the inflammatory reaction and the partial damage of every tissue within the fascial space muscles, nerves, vessels, etc. Muscle is highly specialized tissue with but little power of regeneration, and it is the tissue most affected. Early relief of pressure by fasciotomy has often checked the process.

The pressure within the closed fascial space is the result of swelling from edema, extravasation or hematoma, and these result from venous or partial arterial occlusion, or both, as is so commonly furnished by the unreduced supracondylar fracture. It may also come from any trauma to the contents of the anterior fascial space in the forearm. Whether from fracture of the forearm bones, contusion, crushing, or thermal injury, the vicious circle is started. The greater the swelling, the more is the circulation reduced in the closed space. Casts become tight, especially in front of the flexed elbow These and the tight antecubital skin—stretched from the swelling—occlude the superficial veins and the tight fascia the deep ones all of which veins—both superficial and deep—converge through the antecubital space Partial arterial bloc and pressure complete the picture.

There is, of course, a wide range of degree of intensity of the circulatory interference, so cases may be slight or severe. The process is a factor in producing the terrible crippling from severe infections of hand and forearm, because the intense swelling and intrafascial pressure of the latter impairs the circulation within the closed fascial space. Contractures following muscle rupture or those affecting a few digits following contusion of the forearm muscles are quite different from Volkmann's

Another conception of Volkmann's contracture, started by Leriche and carried on by Griffiths and Foisie, is that the lowered circulation is due to local spasm of the brachial artery from 2 cm. above the elbow down to and including its bifurcation, and secondarily from this to a spasm of its collateral vessels. The reflex of the spasm is thought to be not through the ganglion but low in the nerves about the arteries themselves, started by the trauma at or near the elbow and lasting until relieved by stripping the sympathetics from the artery —or better, by segmental excision of the affected part of the artery, assuming that this is the trigger point that starts the reflex. Frequent reports of local narrowing of artery and of cure by the above means support these claims.

By the closed space conception the phe-

omenon seems sufficiently explained with ut considering vessel spasm . Actual ar erial damage is often found and a local arrowing of the artery may occur from nechanical trauma or drawing out, or from he effects of pressure at the tight bend of he elbow The fascia must be opened to xpose the artery, and this itself is known o cure. Spasm scarcely explains why, of ll parts of the body, the entity occurs in he closed fascial space in the forearm, or vhy the digits or near tissues outside the pace are not also involved In many of he reported cases the cure did not follow t once on the arterial operation, but was lelayed 18 to 24 hours, as after fasciotomy Vould it not seem that if spasm is a factor, t is merely secondary in a case of true Volkmann's ischemia?

Symptoms

Cases vary with the intensity of vessel occlusion, there being several factors deter mining the course. If occlusion is excessive, the course is acute, and in from a few hours to two days such severe damage is done that the whole life outlook of the child is changed, handicapped by a crippled hand. After two weeks of absorption of necrotic tissue and resolution, fibrous con tracture continues through many weeks. If the cast is but moderately tight in the ante cubital space or the cause, whatever it may be, is mild, the process may be insidious and, because the nerves are less affected, without much pain The contracture fol lows even after weeks. It is most impor tant to recognize the condition early and to act sufficiently promptly to avert the catastrophe

The onset is usually sudden and severe, accompanied by much restlessness and the constant intense pain of tightness and of tissues dying from ischemia. The hand and forearm are tense with edematous swelling and are cold, cyanotic, and numb There is pale cyanosis in arterial occlusion, and darker cyanosis when the venous engorgement is primary The hand late may be cold and white In the hand are hypesthesia and paresthesia, and from muscle im pairment the patient has difficulty in mov ing the digits There may be trophic skin

A

B

FIG. 195 Case J A. His arm was caught between two trucks as they side swiped fracturing humerus, radius and ulna which were set at once and the arm enclosed in a cast. Latter was split the second day Severe pain persisted three weeks. Cast removed in nine weeks.

(A and B) Photographs (three years later) taken in flexion and extension show the atrophy limitation of move ment, shortening of muscles of Volk mann's ischemic contracture. Distal two finger segments are anesthetic.

The hand was later operated upon ankylosing the wrist, and using the wrist tendons to move the digits. Nine flexor tendons were lengthened 1½ inches each, and opposition was restored by a pulley operation. A useful hand was obtained.

changes at this stage. Muscles of the forearm are tender and there is tense swelling over the whole mass of flexor muscles, especially in front of the elbow The radial pulse is usually absent but may return in a few days.

On removing the cast, the forearm swells and becomes red blebs and pressure sores may be present. Even on the second day the fingers are semiflexed, and any attempt to extend them increases the pain In two

weeks there starts continuous and progressive, red contracture of the muscles as they shrink and reduce to fibrous tissue. At first they are greatly swollen and much red, reactive hyperemia surrounds them in the process of repair If the forearm is opened early, long, pale, gray pink, friable, necrotic spindles of muscles can be drawn out. Finally, the necrotic muscle is absorbed and replaced by hard, contracted fibrous tissue, considerably shorter than the original muscle, and unyielding Each muscle, tense and homogeneous inside from central necrosis becomes encased in a sheath of fibrous tissue. This peripheral interstitial fibrosis binds and contracts all tissues in the fascial space.

Emerging from this storm is the crippled hand and forearm The extensor muscles are usually spared unless from cast enclosure, but by the flexors the wrist and distal two finger joints are drawn into contracture, though the proximal finger joints are in extension Due to the shortened flexor muscles the digits cannot be passively extended until their flexor tendons are relaxed by increasing the flexion of the wrist.

Nerves are involved in the more severe cases constituting about 60 per cent—the median the most and the radial the least—there being a numb feeling and paresthesia in glove distribution, and partial and in patches complete anesthesia, reaching from fingertips to anywhere from the bases of the fingers to the lower third of the forearm The intrinsic muscles in the hand from lessened nerve action, show atrophy and very little action, thus contributing to the typical claw posture The clawing is exaggerated from firm contracture of the long, deep flexors of fingers and thumb

The whole forearm and hand are shrunken The forearm flexor muscles are hollowed and firm from fibrous atrophy Some of them usually functionate a little. The skin is smooth, cold, and glossy Fingers taper and may show trophic ulcers and deformed nails. Bones are porotic, and in children there may be retarded growth from damage to the epiphyses All of the tissues show poor nutrition. Oscillometer readings are lowered, and so are those of skin temperature The pulse may have returned. Electrically the muscles do not show polar inversion Reaction to the faradic current is less or absent and a greater galvanic is necessary to produce contraction. The elbow may show flexion contracture.

Treatment

Preventive Treatment. In most cases Volkmann's contracture can be prevented. Supracondylar, humeral fractures should be correctly set very early Partial reduction should be avoided Kirschner wire traction or even open operation at which time the vessels are freed may be necessary In a large series treated by overhead skeletal traction there were no occurrences (Dunlop) Fixation of supracondylar fractures by crossed Kirschner wires also avoids this complication. Acute flexion of the elbow is dangerous Whenever applying a cast to an arm, the antecubital space should be kept free, even placing a soft fluff of cotton there to keep away the plaster All freshly casted fractures should, for a few days, be kept elevated Pressure should be avoided along the course of the brachial vessels

Emergency Treatment. By recognizing early signs and anticipating this possibility early when the damage is being done, circulation may be restored in time to avert the disaster First, the limb should be freed of all encircling dressings—especially in the antecubital space. Right angled arm casts should not be merely slit down their anterior or posterior surfaces and spread, as they will not bend in two planes and the pressure in the antecubital space will not be relieved. They should be split full length along both the lateral and medial sides, and the two halves of plaster separated from each other, cutting all dressings down to the skin the full

length. The arm should be elevated Thorough fasciotomy is indicated. The flexor fascia should be split over the length of the muscle bellies and allowed to gape There should be a jog in the incision at the crease of the elbow The most important site for this is the antecubital space across the bicipital fascia The arteries and veins should be clearly inspected and freed from pressure or constriction The fascia should be allowed to gape, but the skin should at once be reclosed for if left exposed and semi necrotic, muscles would be an easy prey to bacteria. Repeated sympathetic block will increase the circulation A supracondylar fracture should even now be set, though Fleming reports a cure by fasciotomy 48 hours after the onset, in which the fracture was not set until one week later The pulse returned in 12 hours and the fingers could be extended. Areas of pressure necrosis from casts should be excised and at once skin grafted, and early the digits and wrist should be splinted in extension and maintained so until the morbid process in the muscles has disappeared.

Later Treatment. Conservative treatment should first be given a good trial By splints the contracted muscles and joints should be slowly, steadily, and gently drawn out, by spring or elastic traction (as in Chap 4) until the contracted tissues grow longer Forceful or intermittent traction is harmful The splints should be removed several times a day for exercise of the fingers. When we draw out the contractures, restore somewhat the muscle balance, and allow exercise, it is surprising to see the improvement in nutrition and use of the hand. First, the digits should be straightened by flexing the wrist and splinted so between two flat, well-padded pieces of metal strapped on them front and back. Extending from the dorsal piece is a lever rod which, when drawn toward the back of the forearm extends the fingers in their proximal joints The cock up splint is then added to dorsiflex the wrist gradually Care

FIG 196 Deformity of Volkmann's ischemic contracture The scar from slough in antecubital space at the site of obstruction is frequently present.

must be used not to traumatize the insensitive fingers. Soft rubber sponge pressure against their pulps can be used to draw them toward a dorsal extension splint. As long as there is improvement, even through several months, this method should be kept up As position of function is obtained and the arm is used actively, more muscle bellies will become active. (For splints, see Figs. 77, 81, 82, 85B) Sympathectomy relieves pain and increases blood supply

After the limit of conservative treatment has been reached, open operation is advisable. First, the length of the flexor fascial compartment in the forearm should be laid open Septa should be severed between the various muscles, allowing their bellies to expand Blood vessels and nerves should be freed throughout their length from strangling cicatricial tissue. The fascial slits should be left open Muscles ruined by fibrous atrophy are best excised and their tendons freed so the digits can extend Each shortened tendon should be liberally lengthened, severing it with a very long longitudinal slit, and after drawing the ends out, reuniting them, overlapping by using a continuous running, removable, stainless steel wire suture brought out through the skin at each end and there fastened by a shot. This tendon lengthening may need to be repeated several times, as the child grows. For the deformity of pronation, the

A

B

FIG. 197 Case G S., age 10. (A) From an unreduced supracondylar fracture occurring a year previously and followed by holding the elbow in acute flexion by adhesive plaster for three days, there occurred a severe Volkmann's ischemic contracture with glove anesthesia. Two months later following an operation the remains of the flexor tendons sloughed from the forearm.

(B) The supracondylar fracture unreduced

(C) Arthrodesis of wrist was done sparing the epiphyseal line and radio-ulnar joint. Both ulnar and median nerves were completely absent from the forearm Later tendon transfers will be done.

C

pronator teres and pronator quadratus may be severed or, if fibrous, excised, and the joints forced into supination

If the muscles are very short, muscle stripping can be done in addition to tendon lengthening. In this, their origins are separated from the medial epicondyle of the humerus and for a length down the radius and ulna, putting the elbow up in flexion for a few weeks, if necessary, to relieve tension on their nerve supply

In cases with severe deformity of flexion at the wrist, in which the muscles are unduly short, much improvement is gained by resecting one or two rows of carpal bones, producing either a false arthroplasty or usually an ankylosis of the wrist in 20° of dorsiflexion If the latter is used, a bone graft should be added to eliminate the risk of nonunion. Arthrodesis has the additional advantage of making the three extensor carpi muscles available for transfer into the flexor tendons of the digits The supinator longus muscle can also be used for this purpose to supplement poor flexor muscles Rarely need we resort to shortening of the radius or ulna, the carpal excision being preferable as nonunion is frequent in this condition. Flexion contracture of the elbow may be relieved by excising the scar tissue there, together with the anterior capsule of the joint.

FIG. 197 (D) A direct flap of abdominal skin was applied to the wrist to replace cicatrix, help nutrition and to provide a bed *through which transferred extensor* tendons to flexors can glide.

ISCHEMIC CONTRACTURE, LOCAL, IN THE HAND *

An interesting entity newly recognized in the hand is fibrous contracture of its intrinsic muscles that is quite similar in pathology to Volkmann's ischemic contracture in the forearm. Resulting in typical deformity, it is easily recognized by a few simple tests *It is disabling, but can be* improved by surgery

Incidence In the great concentration of crippled hands during the last war, several score of such cases were encountered Now, two years later, the leftover dregs or tough hand cases in the Army are being seen and *it is found that among them this entity is* very common

Etiology Many give the history of injury to arm or hand followed by application of a plaster cast well down over the fingers and often clumping the thumb into the hand. The resultant swelling of the hand in the unyielding cast so expressed the blood supply that the intrinsic muscles of the hand underwent *fibrous degeneration and contracture* and, also, to a lesser extent, the other tissues in the hand

Many other cases give the history of injury to the brachial plexus or large arm nerves followed by application of a plaster cast which included the hand A good proportion of these had injury to the axillary and brachial arteries, and the pulse at *examination* was *small* or absent. Some had lost both radial and ulnar arteries from an explosion wound at the wrist Another was from a severe cut through these two arteries high in the forearm Some were burn cases, the muscles having been rendered ischemic from a too constricting pres*sure dressing* Though most limbs had swelled in casts, some of those with injury had not been enclosed in casts, the *tight*

* Read before the Amer Soc. for Surg of the Hand, Jan. 24 1948.

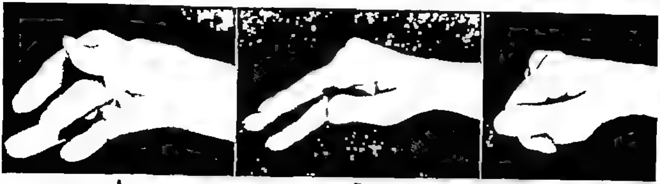

FIG. 198 (A and B) Local ischemic contracture of intrinsic muscles of the hand due to nerve and vascular injury in upper arm. Fibrotic contraction of the interossei flexes the proximal finger *joints* and *extends the distal two and of the thenar muscles* clumps the thumb into the palm It is necessary to excise or strip these muscles to restore balance.

(C) When patient relaxes the interossei by flexing the proximal finger joints he can also flex the distal two finger joints. (Courtesy of L. D Howard Lt. Col. M C., Wakeman General Hospital.)

swelling and poor nutrition of the hand producing the same result.

The same phenomenon occurred in all due to lessened circulation. There resulted fibrous degeneration and contracture, especially of the intrinsic muscles of the hand, and tissue changes and poor nutrition throughout the hand Any one or several intrinsic muscles may show fibrous contracture due to local injury, such as gunshot wound or burn. Though entirely different in etiology, due to cicatrix and adhesions, they give the same test as does the muscle that has been contracted from ischemia. From a burn on the dorsum of the hand it is common to find the extensor mechanism adherent and the underlying interossei contracted, thus tying the function of each.

A similar condition from ischemia may commonly be seen in the foot. An example is of a soldier shot two years ago at the groin through the femoral artery and sciatic nerve The foot showed dorsal pigmentation and an ulcer from poor circulation, and another ulcer was present under the fourth metacarpal The toes showed the same test

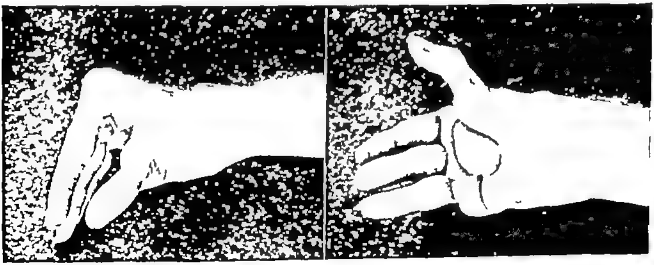

FIG. 199 Local ischemic contracture of intrinsic muscles of hand due to compression from encasement in plaster after injury from shell fragment. Little finger became gangrenous Shows typical deformity of thumb drawn into *the hand from contra*cture of the thenar muscles, flexion of proximal and extension of distal two finger joints from fibrous contracture of the interossei muscles. Pedicle had been applied to the palm but contracture was not due to skin. Needs stripping or excision of interossei and thenar muscles and a bone *strut to spread* the first two metacarpals. (Courtesy of L. D Howard Lt. Col., M.C., Wakeman General Hospital.)

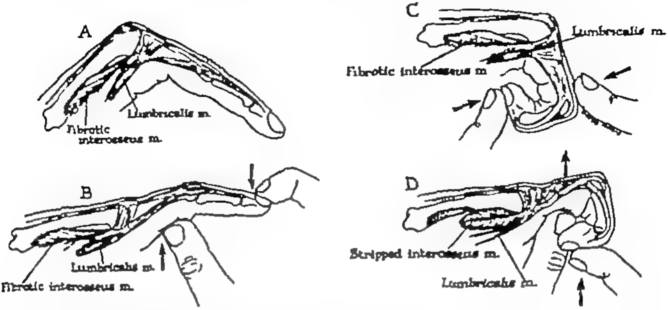

FIG. 200 (A) "Intrinsic plus" position with fibrotic intrinsic muscles holding the proximal finger joint in flexion and the distal two joints in extension.
(B) and (C) show test for intrinsic contracture. When the intrinsic muscles are tensed by holding the proximal joint in extension, the distal two joints cannot be flexed but when they are slackened by flexing the proximal joints the distal two joints flex.
(D) When the interosseus muscle is stripped and advanced, the distal two joints flex even when the proximal joint is held extended. (Courtesy of American Journal of Plastic and Reconstructive Surgery)

of muscle imbalance from contracture as explained later for the hand and assumed the same position with proximal joint flexed and distal two joints extended Another was of a soldier in whom both popliteal nerves and the artery were injured

Symptoms. The deformity, or position of muscle imbalance, directs the attention toward the diagnosis. In intrinsic paralysis there is claw hand, flat hand, and the thumb is at the side. In intrinsic spasm, or contracture, on the other hand, the thumb is straight, is clumped into the hand, and the fingers are straight in their distal two joints but flexed in their proximal joints The palmar arch is exaggerated The first of these positions from imbalance may be called intrinsic minus, and the second intrinsic plus In the entity described, the position is that of intrinsic plus as the intrinsic muscles are in fibrous contracture. The position assumed is somewhat like that of a hand about to enter the sleeve of a coat

The thumb is held straight but drawn into the palm near the second and third metacarpals. The angle between the first two metacarpals is narrowed because of the cicatrix between them and the adductors and first interosseus muscles which have contracted due to scar From the contracture in the cleft the carpometacarpal joint may become hyperextended instead of flexed

The fingers are drawn by the cords of the fibrous muscles, lumbricals and interossei into flexion in their proximal joints and extension in their distal two Exaggeration of the metacarpal arch causes the fingers to converge.

Hollows from atrophy are to be seen just as in combined median and ulnar palsy, as the interossei, thenar and hypothenar muscles have atrophied in fibrous contracture. With this atrophy the appearance is that of palsy of the intrinsic muscles, though the deformity is opposite The whole hand is poor in nutrition because of the squeezing out of its blood supply from swelling in the cast, or because of interruption of the blood vessels of the arm.

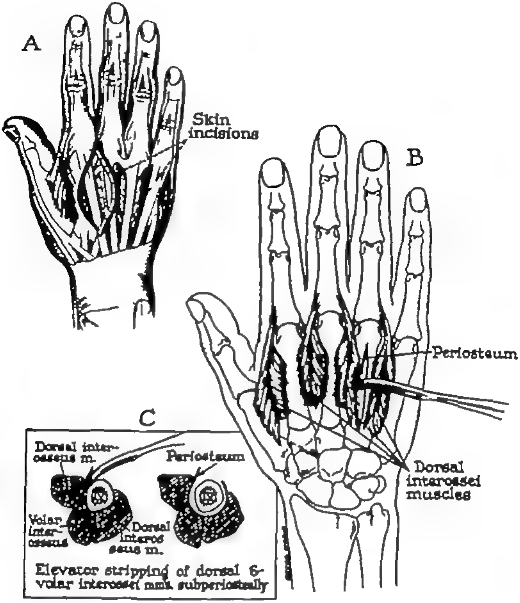

Fig. 201 Illustrating operation of stripping and advancing interosseus muscles to allow extension of the proximal finger joints and flexion of the distal two joints.
(A) Two incisions
(B) Muscles freed from bones and advanced enough to allow full motion.
(C) Curved separator used to detach muscles from metacarpals.
(Courtesy of American Journal of Plastic and Reconstructive Surgery)

All tissues were affected, and the muscles more so The fibrous change is irreversible. The hand when grasped feels firm and stiff The pulse is present, except in those cases in which there was interruption of the main artery of the limb, when it is weak or absent.

Some of the thenar or intrinsic muscles may be affected more than others Thus we may feel in one thenar eminence the adductors reduced to a palpable fibrous band and in another the flexors or the abductor or opponens muscles. In one case a lumbrical only was involved.

There is every degree of involvement, from extreme cases to mild ones which show the condition in only a few digits. In severe cases the muscles are reduced to fibrous cords and no longer have active contraction. In milder ones, the muscle is fibrous and shortened but still has considerable voluntary action. This may be de-

FIG 202 (*Top left*) Local ischemic contracture. History of tight cast holding hand clumped because of fracture of humerus. Contracture is worst in thenar adductors and the interossei of the first two digits, but affects all intrinsic muscles.

(*Right top and bottom*) Corrected muscle balance allows function and position of function. The thenar adductors were disconnected, the interossei were stripped from the metacarpals and postoperative fixation was in the position of claw hand. (Courtesy of Donald R Pratt Lt. Col M C., Dibble General Hospital)

termined by feeling the lateral bands as the distal finger joints are moved and by observing the ability to extend voluntarily the distal two finger joints without using the long extensor

TEST FOR CONTRACTURE OF INTRINSIC MUSCLES TO FINGERS If we tense the interossei by holding the proximal joint in extension the distal two joints cannot be passively or voluntarily flexed But if we slacken the interossei by flexing the proximal joints the distal two joints flex readily The examiner strains the proximal finger joint firmly in hyperextension, thus tensing the interossei Then tapping on the finger nail meets with firm resistance, the distal two finger joints standing out stiff and straight.

This is similar to the test for fixation by adhesions of a long extensor tendon on the dorsum of the hand but in this case when we hold the proximal joint on a strain in flexion, we cannot force the distal joints into flexion When the proximal joint is allowed to extend, the distal two joints flex freely The extensor tendon may be adherent and the interosseus muscles contracted in the same hand, thus responding to both tests Even flexion adhesions in the palm may complicate the picture A similar but reverse test discloses this

Contracture of thenar muscles is determined by the inability to draw out the thumb into abduction or opposition, atrophy of the thenar eminence and a feeling of firmness with palpable fibrous bands in the thenar muscles There is little or no voluntary action of the base of the thumb

These hands have little function Neither the fingers nor the thumb may open for

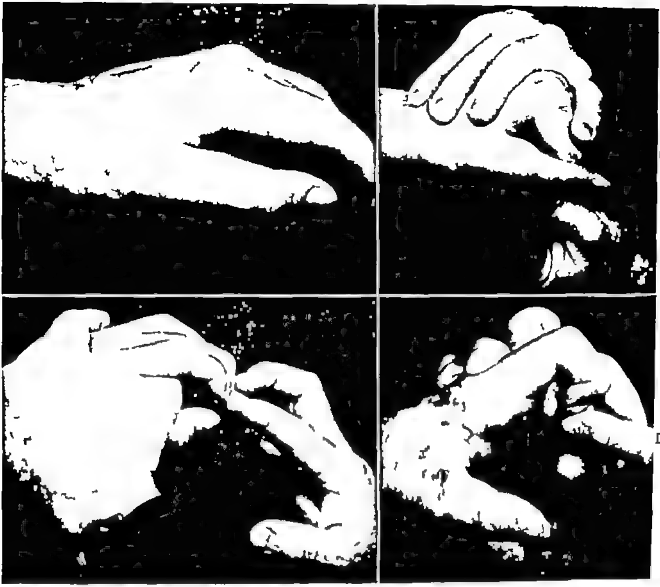

FIG. 203 Ischemic contracture of intrinsic muscles in the hand due to impaired circulation following fractures from shell fragments of shoulder, forearm, and wrist

(A) Thumb in adduction contracture and fingers in typical position produced by contracture of the interosseus muscles.

(B) When the proximal finger joint is extended, the distal two cannot be flexed.

(C) When the proximal finger joint is flexed, the distal two joints will flex.

(D) Postoperatively after the thumb cleft was opened by a plastic maneuver and the interosseus muscles were stripped the fingers could then flex while their proximal joints were held extended, and the thumb cleft was wide.

grasp and there is, in general, poor nutrition The hand cannot assume the position of function. The intrinsic-plus condition is as crippling as that of the intrinsic minus

Treatment. If it is recognized early that the condition is impending, it may be prophylactic to slit open the fascial covering of each intrinsic muscle. Only in a mild case can position be improved by splinting It is necessary either to excise or sever the fibrous contracted muscles, or, if they are still active, to strip them to displace their bellies distalward or elongate their tendons Our aim should be to achieve the position of function and give as much motion as possible from this position in both extension and flexion

THUMB Here the problem is to open the angle between the first two metacarpals, to maintain it so, either with or without motion, and to furnish sufficient skin for a wide cleft.

Through a dorsal incision bisecting the cleft, and usually carried across the web to

parallel the thenar crease, all fibrous contracting tissue and inactive parts of the thenar muscles are excised If the adductors are active but too short, the tension may be relieved by pushing off with the handle of a scalpel their origin from the third metacarpal. Even part of the capsule of the carpometacarpal joint of the thumb may need cutting to allow full abduction and opposition of the thumb One should guard against wounding the radial artery deep in the cleft.

The thumb will again draw into the palm and toward the second and third metacarpals unless guarded against by a pulley transfer operation for opposition, a temporary transfixion at a wide angle of the metacarpals of the cleft by cross-pinning them with Kirschner wires, or by holding the thumb in moderate abduction and opposition permanently by a bone block in the angle or a cross bone graft.

The defect in skin is then closed by a flap of skin from the abdomen in one procedure tubing the base of the flap After three weeks it is detached from the abdomen A thick split-skin graft may be used instead, but it will be less satisfactory

Fingers. In the fingers, correction of deformity and imbalance is done, either saving the remaining function of the interosseus muscles or discarding any hope of this Decision depends on whether the interosseus muscles are active or are entirely reduced to scar

If the muscles are active, though shortened, a stripping operation is done through two longitudinal dorsal incisions, two through each The muscles are freed from the bones and allowed to displace distalward The fingers, now free from restraint, are put up in moderate claw position for about two weeks It is also possible to lengthen the tendon of the interosseus muscle by cutting through it long and obliquely, and resuturing

Should the contracted muscles be no longer active, a tenotomy may be done on the tendon to the lateral band on the side of the finger opposite the proximal finger joint wherever needed. This, theoretically, would cause clawing, but, practically, there is a tendency for the contracture to recur If clawing should occur later, the sublimis tendon may be transferred to the lateral band or the M P joint fused in flexion.

By the above measures, both the position of function and improved function can be obtained. There will, of course, be a residue of fibrosis in the hand which will gradually improve with use

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6

Bones

CORRECTION OF DEFORMITIES
RECONSTRUCTION AFTER GUNSHOT WOUNDS OF METACARPALS
TRAUMATIC DEGENERATION OF CARPAL BONES

This chapter concerns bones from the standpoint of reconstruction, and deals with deformities, malunion, nonunion, acquired defects, and avascular degeneration.

Operations on the bones should follow replacement of cicatrix by good skin and should precede the repair of tendons

CORRECTION OF DEFORMITIES

Malunion. When fractures of the bones of the forearm, the metacarpals, or the phalanges unite in abnormal positions the natural mechanics of the part are upset, resulting in turn in strain, pain, and disability In malunion, tendons pull at wrong angles and with the wrong leverage. If the bones in the hand are at an angle muscle balance of the digits is upset, with consequent deformity and disability For instance, if metacarpals unite in sharp flexion the flexor tendons will be relaxed and the extensor tendons tightened. The proximal finger joints will then go into hyperextension and the distal two finger joints into flexion.

In a malunited Colles fracture with the distal fragment cocked back and the fractured part of the radius protruding into the line of pull of the flexor tendons, there will be pain on activation of the latter pulling around the bony prominence and the muscle balance will be upset in that the flexor tendons will be made too tight and the extensor tendons too loose.

Angulation in a limb from malunion or dislocation upsets the balanced tension of the muscles spanning from forearm to digits, causing compensatory and opposite angulations of the joints serially down the limb If the lower ends of the forearm bones are angulated volarward, or there is a dislocation backward of carpus, metacarpus or metacarpals on the carpus or malunion of the metacarpals with dorsal bowing, the consequent tightening of the long extensors in being stretched over these convexities hyperextends the proximal finger joints This in turn tightens the long flexor tendons to draw the distal two finger joints into flexion Correction of the alignment immediately restores muscle balance, allowing the hand and wrist to assume again the position of function.

Due to malunion of metacarpals and phalanges the digits may on flexion or extension move entirely out of their normal course in either a spreading or converging way, or the thumb and digits may no longer move along their correct planes of motion and so may no longer oppose each other

Deformities of malunion are rotary, angulatory, or overlapping In rotary deformity of the metacarpals or proximal or middle phalanges, the axes of the joints distal to the fracture will be tipped, so that on flexion the digits may converge crossing each other, or may diverge. Normally, on flexion the fingers should converge toward the tubercle of the navicular bone.

Angular deformity is often quite conspicuous from a cosmetic point of view, whether it be in the anteroposterior or the lateral planes. In malunion of the metacarpals the distal fragment is usually angulated volarward. This leaves the head of the metacarpal projecting prominently in the palm, and when the dorsal aspect of the hand is viewed it will be seen that that knuckle has dropped and is out of alignment with the other knuckles There may be pain and tenderness in the palm due to pressure on the volar digital nerves by the projecting metacarpal head There must be either the usual projection of the head into the palm or else a dorsal projection of the shaft at the angulation.

The deformity in the proximal phalanx is usually with the distal fragment angulating dorsalward, in which case on full flexion the finger lacks considerable of reaching the distal crease in the palm The angulation dorsalward is subtracted from the amount of flexion of the finger If the deformity happens to be volarward, there is a similar loss of extension of the finger

Overlapping deformity of a metacarpal or a phalanx results in shortening of the digit. Also, as the bone ends project against the flexor and extensor tendons there is a tendency, just as there is in angular deformity, for the tendons to be caught in the callus

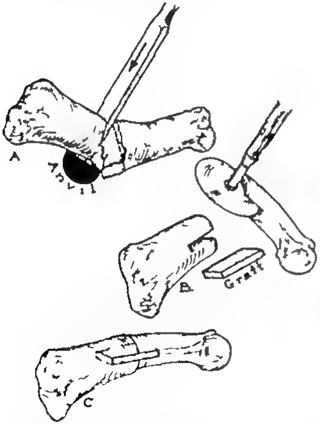

FIG 204 Bone carpentry A small key bone graft and a good fit assure against nonunion. The point of an anvil is held under the phalanx to facilitate carving with an osteotome. A bone graft may be easily obtained by chiseling off a chip from the ulna of the same arm below the elbow

FIG. 205 Handy anvil for carving small bones with sharp osteotome. When the point is placed under the bone the heavy base is in the line of the stroke.

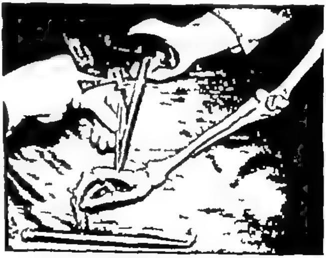

FIG. 206 Anvil on the principle of pull instead of push. Through a small incision it hooks around a bone bracing it by virtue of the inertia of the heavy mass, so that the bone may be carved by an osteotome held parallel to the handle Detachable hooks of graded sizes fit any bone from phalanx to femur

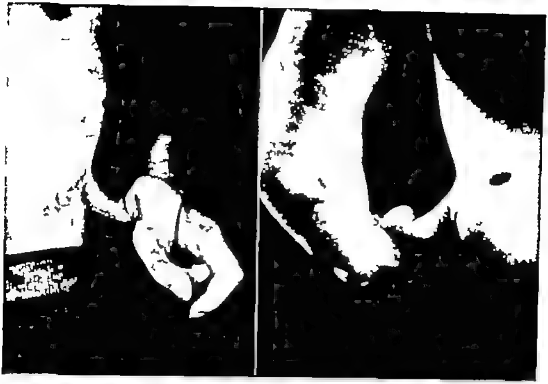

FIG. 207 Osteotomy of thumb metacarpal and pedicle correcting cleft applied at same time. Pattern on a tube allows hand to be positioned far away from side. (Courtesy of L D Howard, Lt. Col., M.C., Wakeman General Hospital.)

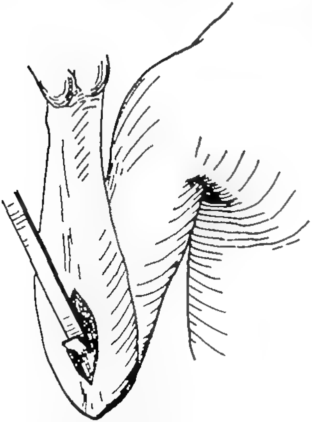

FIG. 208 A convenient method of obtaining a small key bone graft from the ulna with which to unite a metacarpal or a phalanx.

of the bony union. Much disability results from fracture of the phalanges due to adhesions of the flexor or extensor tendons causing loss of motion in the fingers.

Bone Carpentry Nonunion, malunion and defects in the metacarpals and phalanges are corrected by physiologic bone carpentry First the cicatrix must be excised *and a good covering furnished by* either sliding dorsal skin and skin grafting where it was, filleting a finger and laying its skin over the defect or by a preliminary pedicle graft from the abdomen. The malunited bones should be disconnected, and rejoined in their normal positions, so that once more the fingers will extend and flex in their proper planes and the fingers and thumb will oppose each other in a functioning manner *The positions of the bones* should be so corrected that the tendons will again move in their proper straight courses have their proper angle of approach to the joints and that normal leverage and proper muscle balance will be restored. Only when the mechanics of the hand are again correct will good function be restored.

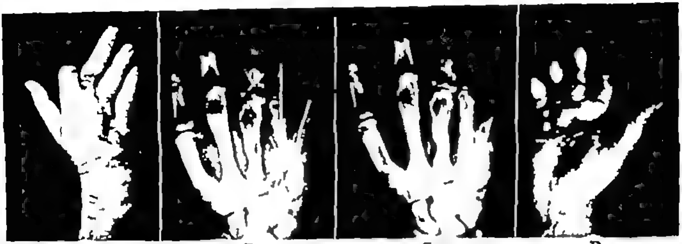
A B C D

FIG. 209 (A) A machine gun bullet injured the dorsal aspect and the bones diagonally across the hand. (B) The bones were repaired by grafts and pinning. (C) Bony union (D) The hand gained stability and enough flexion to grasp large objects. (Courtesy of William H. Frackelton, Lt. Col., M.C., Beaumont General Hospital.)

Following open operation a metacarpal or phalanx may not unite There is a distinct tendency not to unite, therefore, it is wise in rejoining these bones always to do one or both of two procedures. One is to pin the bones firmly together The other is to insert a small bone graft. This will not only aid in holding the bones in position by acting as a key, but will insure union A graft for such purpose may be a small, flat chip of bone chiseled from one of the long bones, preferably from the proximal half of the ulna, which is already prepared in the operative field and so is quite handy Through a short incision near the elbow uncovering the ulna, by a chisel and a few strokes of the mallet, a thick chip of bone is obtained. By a few cuts with the scissors this is shaped into a rectangle. Into each end of the metacarpal or phalanx to be united a saw cut from side to side is made for about 1 cm deep This may be spread slightly if necessary by a rotary motion with a chisel. Into these two slits the bone graft is fitted, and over it the ends of the bone are shoved together It will be found

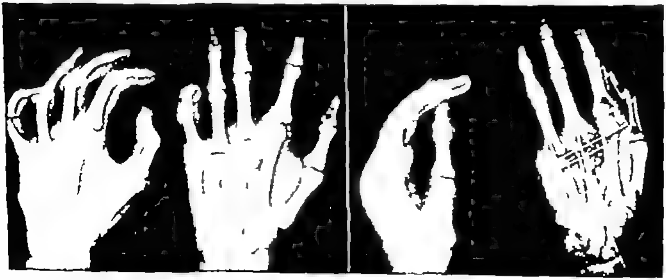

FIG. 210 Third metacarpal was repaired by key bone graft. Fourth metacarpal was removed Fifth metacarpal was jogged over to place of fourth, pinning all securely enough to do capsulectomies of the proximal finger joints. (Courtesy of Donald R. Pratt, Lt. Col., M.C., Dibble General Hospital.)

Fig 211 Case E S Arthritic finger joints from x ray burn ankylosed by bone carpentry

that the bone fragments will then remain firmly in place without a chance for angulatory or rotary deformity

As in all bone work throughout surgery accurate cabinet fits should be made, so that the bony surfaces will be accurately approximated and held in place so firmly that they will hold until a splint is applied. Such junctions will unite They should be made in a massive manner, with broad surfaces approximating each other If one attempts to join these bones by making the layers of bone too thin, even though dovetailing them, it will be found that the union will melt away from insufficient blood supply Our cabinet work should be accurate, but the parts of bone that are in contact should be massive. Bone ends contacted inaccurately, in a nonworkman like manner, so they are free to move, frequently result in nonunion, because each time a vascular bridge forms it will be sheared or broken until the repair effort ends and pseudarthrosis results. Certain mechanical aids facilitate the accurate shaping of bone ends one is the use of an anvil, with a pointed end, which fits behind the phalanx or metacarpal and still has a heavy base directly under the point. Both the base and the point are offset from a common stem The result is that when a sharp osteotome is driven across the phalanx, braced against the point of the anvil, the cutting will be as accurate as in carving an ornament out of ivory It is important to hold the anvil exactly in the line of the chisel and the bone edge close against the anvil. Another type of anvil the point of which can be slipped around the bone through a small incision is shown in Figure 206 *

Another useful tool for these small bones is the motor-driven handy through a sterile, flexible shaft. From the dental supply stores one may obtain fine circular saws, routers, gouges, and many other intriguing instruments that can be snapped into place for the particular cut desired

All the principles of repairing bones in general apply equally to those in the hand. The periosteum should be preserved with its attachment to the soft parts intact and if necessary some additional osteoperiosteal or cancellous chips can be laid around the fracture line. Fortunately ample bone is available for any size of graft. A useful principle is to thrust the point of a bone or graft into a cancellous portion such as the carpus or metacarpal head or the end of a phalanx so as to obtain firm fixation and ample contact to insure union. Grafts should, as elsewhere, contact endosteum as well as periosteal and compact bone with maximal surface, thus obtaining blood supply and growth from each side. Fragments of these small bones may be fastened together by fine stainless steel wire No 35 through drill holes. This approximates the bones but the fixation depends on splinting It is preferable to pin them firmly together and to adjoining metacarpals as described below under Grafts

In all metacarpal reconstruction the condition of the surrounding soft parts must be

* Both obtainable from H. Weneger 143 Valencia St., San Francisco, Calif.

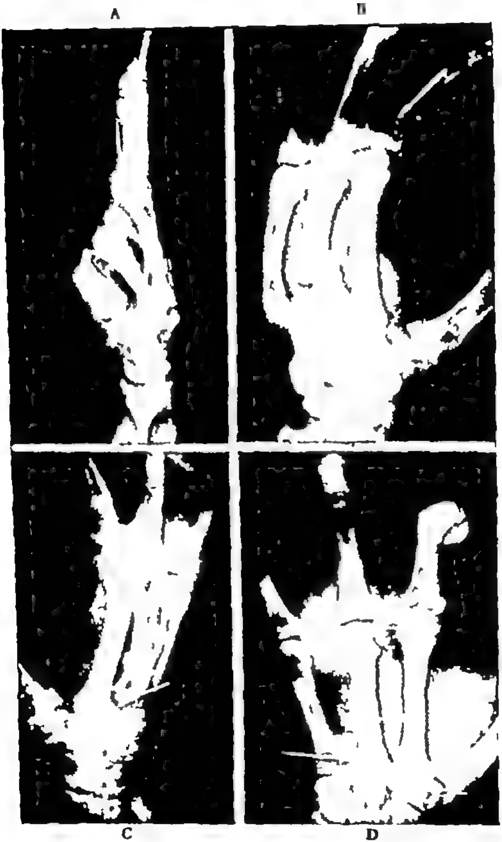

FIG. 212 (A and B) Malunited fracture of third metacarpal the head projecting as a sensitive prominence in the palm. Posterior dislocation of base of third metacarpal caused imbalance of muscles.

(C and D) Fracture and dislocation corrected, the latter being held in place by a stainless-steel pin through the skin.

FIG. 213 Case F C. A.
(A) Bone graft placed in metacarpal in 1921 after bullet wound.
(B) Specimen removed two years later because from loss of nerves little finger became stiff and atrophied.

considered. If the interossei are destroyed the distal two joints of the fingers will not extend, i.e., the fingers will claw In this case one must either excise the ray or provide a substitute for the intrinsic muscles (See Chapters 7 and 10) If too many structures about the metacarpal are destroyed or are cicatricial, the ray should be excised

Grafting for Bone Defects. Defects left by curetting out cyst cavities where the main bone is still intact are readily filled by spongy bone obtained with a curette from the head of the tibia or iliac crest. If the defect from cyst or tumor is across the shaft, a solid graft is necessary Following gunshot wounds and many civil injuries there is often a defect in any part of one or more metacarpals necessitating bone grafting By grafts, length, continuity and restoration of stability of the digits are readily accomplished.

Grafts are obtained from ulna, tibia, rib, iliac crest or another finger bone. For speed the ulna is most handy The field already sterilized is presented by merely flexing the elbow With a motor saw the graft is cut from near the upper end If grafts are needed for several metacarpals the anteromedial surface of the upper end of the tibia is better After making two parallel cuts two oblique ones are made at each end This gives a double-pointed graft which may be thrust into the head, base or shaft of a metacarpal or into the carpus. Rib or iliac crest has the big advantage that bone healing is firm in five weeks while with the hard bone of the ulna or tibia it takes from

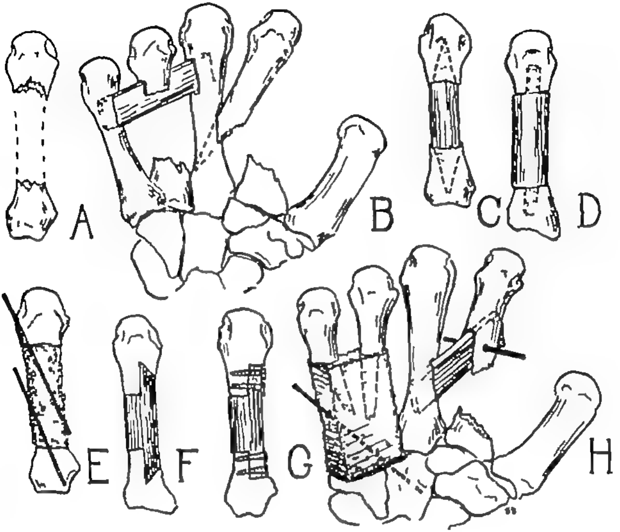

FIG. 214 (A) For absence of the metacarpal shaft, support for the metacarpal head may be supplied by various types of bone carpentry

(B) Transverse cortical graft from ulna or tibia. Index metacarpal may be spiked into the long.

(C) Graft sawed from ulna or tibia may be spiked into the head and base. (At one end a slot is cut so that the spike may be inserted without losing length.)

(D) Cortical graft is nibbled with a rongeur like a rolling pin. Here, also a slot is needed. If based on the carpus pressure holds graft into a slight indentation.

(E) Iliac cancellous graft, based squarely is pinned firmly in place. Cancellous bone has the great advantage of uniting in 5 weeks whereas cortical grafts take 2 or 3 months.

(F and G) Two types of inlay

(H) Iliac graft based on carpus supports two metacarpal heads, and for stability is pinned by Kirschner wires. Index metacarpal is fixed by cortical bone graft to that of long.

two to three months Long fixation stiffens a hand The graft in response to function, in time becomes amply strong as from hard bone. Cancellous bone graft weathers infection better than cortical An exposed surface chiseled off may show bleeding bone and may take a skin graft The iliac crest is thicker at each end the rear end being the larger supply The surface cortex may be taken with the graft or raised and replaced taking the graft from beneath.

Grafts from hard bone may be pointed at each end, shaped like a potato masher for medullary insertion at each end or stepped at each end to use as an onlay, the center of the graft in each case being of the thickness of the shaft. There are many ways of shaping and placing bone grafts in the hand some by pinning and some by such close and engaging fits that no other fixation is necessary These are shown in the illustrations.

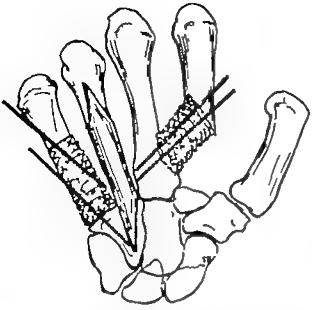

Fig 215 For absence of bases of the metacarpals the bone graft, if cancellous from ilium may rest pinned in place on the carpus or if cortical, as in the fourth meta carpal, it may be spiked into place. For loss of base of index metacarpal an iliac bone is pinned to the long metacarpal or to carpus.

Rib grafts can be used by impaling or contacting them with a flat end Grafts *from iliac crest are quickly cut out with* an osteotome, cylindrical, ample in size and with broad flat ends Grafts of cancel lous bone from rib or iliac crest, aside from their quick healing, have the advantage that holding pins may be thrust through them in any direction. When the bases and shafts of several metacarpals need replacement, a *flat outer slab of ilium* is carved off with an osteotome starting at the crest. One tapering edge is embedded in the carpus and the other in slits in the metacarpal necks. All is pinned firmly in place.

Stability by Pinning Our bone con struction should be firm both to assure union and so that, at the same time, the proximal finger joints can be placed in flexion through capsulectomy without disaligning the bones If bones are pinned quite firmly, very little

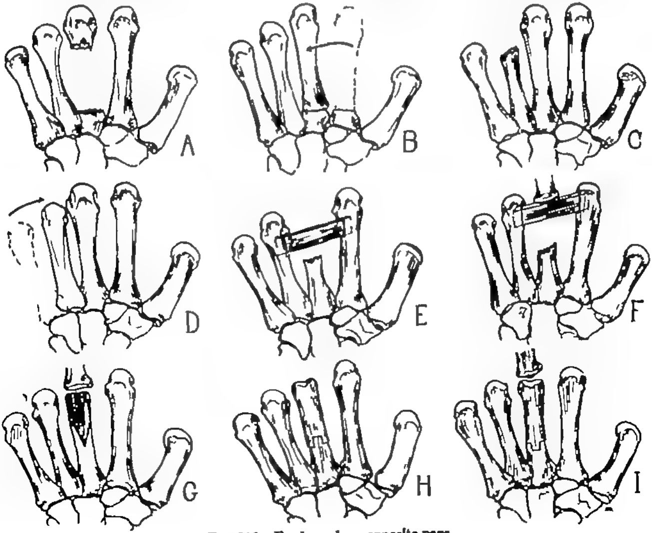

Fig. 216 For legend see opposite page.

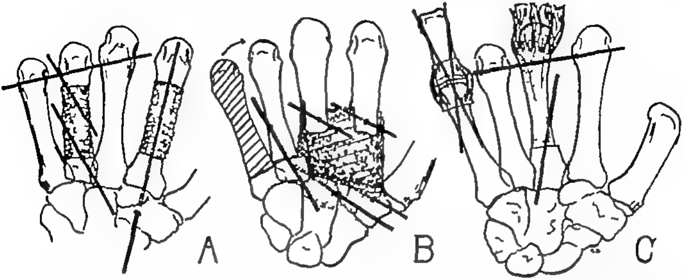

FIG. 217 (A) Methods of pinning iliac grafts in place. If made firm capsulectomy may be done at the same time. As shown in the index metacarpal, the pin is inserted through the head and made to emerge through the skin in back of the flexed wrist. It is withdrawn here just to clear the joint and motion of the wrist is stopped with plaster

(B) Using iliac grafts to support two metacarpals The graft is slotted into the carpus each metacarpal and pinned in place. The metacarpal of the little finger has been jogged over to take the place of the ring finger and pinned there.

(C) Free graft of joint from toe or finger to act as the proximal joint of the little finger Bones are pinned firmly into place. Free graft of the fifth metacarpal plus joint capsule to replace distal two-thirds of a metacarpal and half of the proximal finger joint. Both operations have been successful.

splinting is needed. Fine Kirschner stainless steel wires are drilled through the bones by hand or else by motor drill for speed, ease and accuracy They drill well if merely cut off obliquely with a wire cutter If used in a pin vise, the wire may be bent to a right angle where it projects through the vise so it will serve as a handle. Several are placed in different directions obliquely, through the metacarpal and carpus, obliquely through the two portions of bone or graft transversely pinning several metacarpals together through heads, shafts or bases, or longitudinally down the center When an oblique wire is placed it may be pointed at each end It is drilled into the open end of one bone and then reversed up through the open end of the other In placing a longitudinal wire the proximal finger joint is flexed and the wire is drilled through the metacarpal head down the length of the metacarpal and graft and on out the skin over the flexed wrist, which is then splinted From here the wire is withdrawn until it

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FIG. 216 (*Opposite page*) Problem of loss of head of one of two central metacarpals which causes the fingers to cross on flexion.

(A) Head of third metacarpal must be removed because of too much cicatrix and damage to the soft parts. The finger is filleted and the skin used to cover the dorsum of the hand

(B) Therefore, the nearest marginal ray (index) is jogged over in its place by osteotomy thereby giving the heads mutual support and loosening the hand by narrowing it.

(C and D) When head of ring metacarpal is lost the remainder of the shaft is removed and the fifth metacarpal is severed from the carpus and dislocated to take the place of the fourth. The base of the ring metacarpal need not be preserved, as it is the only one to which a wrist extensor does not attach.

(E) Transverse graft used to brace adjoining metacarpals and to keep them from rotating after loss of a central head The long finger is filleted to use for skin defect and amputated

(F and G) Two operations of bone graft and arthroplasty of the joint which do not yield sufficient motion to be practical.

(H) Recessing a proximal phalanx to build out a metacarpal aligning the phalangeal head with those of the metacarpals for mutual support. The finger is amputated.

(I) Same, but preserving the finger which is then one segment short.

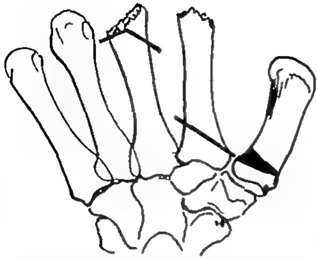


FIG. 218 If the heads of both the second and third metacarpals are absent, the second should be removed near its base. Whatever is left of the third should be preserved to support a pad against which the thumb will work. A rotary angulatory osteotomy should be done on the base of the first metacarpal so that the thumb will work without strain against the ring and little fingers.

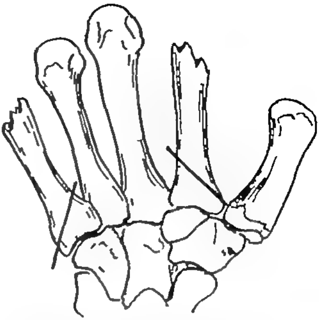


FIG. 219 If the head of either marginal metacarpal is gone, the remainder of that metacarpal should be removed obliquely at its base, leaving the insertion of the wrist extensor in place.

just clears the articular cartilage of the head and is then cut off at the wrist beneath the skin for withdrawal later The wires are usually not left protruding through the skin as movement leads to infection They are clipped off just beneath the skin to be removed under novocain with pincers as soon as union is apparent by x ray Phalanges are usually pinned by two pins crossed to prevent distraction, and routinely so for arthrodesis As the pins are inserted the bone ends should be clamped tightly together with two towel clips Here a small key bone graft helps union. Bone problems of the thumb and the partial hand are described under Reconstruction of the *Thumb Chapter 10*

Approach to the phalanges should be through midlateral incisions and to the metacarpals through longitudinal dorsal incisions. The thumb metacarpal may be uncovered by an excellent exposure, using a transverse incision along the creases around the base of the thenar eminence till over the metacarpal base and then extending distally along this bone. The muscles are stripped volarward from the metacarpal and then replaced.

On completing the bone operation a nonpadded half plaster of Paris cast may be applied to the volar half or two-thirds of the hand. Over the hand and also this part of the cast should then be laid a piece of wax paper, and over this another slab of plaster, thus making a bivalve cast. The volar cast should fit around the hand and fingers sufficiently and even to two-thirds of their circumference to hold the bones in place. The dorsal member of the cast should, before 24 hours have elapsed, be lifted a little to allow for swelling, spreading the cast if necessary and as the swelling gradually decreases should be kept snugged up against the volar half A circular non padded cast should never be placed about a digit which has been operated upon, as necrosis would then be quite certain to occur

When the bones have been securely fastened together so they are firm, it is better instead of applying a cast, to pack all firmly filling all interstices with voluminous waste or *fluffed gauze* and *wrap around* with an elastic bandage. At the first dressing in six days, when the swelling is less, a half cast may be applied. Motion makes

nonunion and infection Proximal finger joints, when immobilized, should, if possible, be in flexion lest they stiffen in extension

A fresh fracture of a phalanx or metacarpal will unite firmly in three weeks, but in a secondary repair using a bone graft it is best to immobilize for from five to eight weeks, being guided by the roentgen appearance. Whenever a plaster cast is applied to the hand, as much as possible of the undamaged digits should remain uncovered by the plaster so they will be free to move This will not only prevent these digits from stiffening, but will also keep the whole hand more mobile and in better repair Sometimes the bases of the two digits adjoining the finger operated upon should be incorporated in the plaster, because movements of adjoining digits, considering that they are motivated by a common muscle, tend to angulate the fracture, if insecure. In order to leave a finger free to move, the cast should terminate at the distal crease in the palm and for the thumb at the thenar crease For a fracture of a phalanx or metacarpal the cast should include the forearm and the wrist should be in moderate dorsiflexion.

FIG. 220 Case R. M. D
(A) Malunion of proximal phalanx. Had been set two months previously on a roller bandage. Muscle imbalance caused the finger to be flexed.
(B and C) Point of distal fragment was impaled into the proximal one and bone chips from ulna were packed about the juncture. One stainless steel wire.
(D) Restoration of shaft.

Crossed Fingers Fingers cross on flexion for various reasons as noted above. Malunion of metacarpal or phalanx in rotation tips the joint axis so the finger crosses or diverges, and loss of the support of the head of a central metacarpal allows the adjoining ones to rotate towards each other, tipping their axes so the fingers cross. Excessive tipping causes the fingers to cross in moderate flexion, but to diverge in full flexion. Treatment is given in this chapter

FIG. 221 Case H. S
(*Top*) Due to injury of the middle finger joint the middle and proximal phalanges were ankylosed to each other using a small key bone graft chip from the ulna.
(*Bottom*) Union.

When the intervening metacarpal head is missing, fingers may diverge on flexion due to contracting cicatrix on the dorsum, rolling the two metacarpal heads backwards towards each other and tipping their joint axes. This may neutralize or nullify the effect from the missing head Similarly a volar contracting scar will exaggerate the crossing on flexion

RECONSTRUCTION AFTER GUN SHOT WOUNDS OF META CARPALS

Gunshot wounds through metacarpals are crippling as they are far reaching in their destruction. About the bone are closely grouped many vulnerable structures, any or all of which may be injured Such a lesion, if severe shows wide destruction of skin usually dorsal, resulting in extensive cicatrix. The extensor and flexor sublimis and profundus tendons may be destroyed and also the volar digital nerves Intrinsic hand muscles share in the destruction as they are close to the bones The proximal finger joints of that finger, and often also of all, are usually stiff and straight. The whole hand is so firmly indurated from contracting cicatrix that the nutrition is poor, there being atrophy and stiffened joints throughout. The metacarpals are often malunited, buckling backward or having shortening or nonunion from defects of head, shaft or base and they are frequently multiple They may be dislocated backward from the carpus.

The degree of disability may be lessened by selective early treatment (see Chapters 12 and 13) Early traction prevents malunion Traction with the proximal finger joints in flexion prevents that joint from becoming stiff and straight. Early closure of wounds by skin graft avoids the general stiffening from long infection. Casts should not enclose too much of the hand, should immobilize the injured parts but allow motion of the well parts. The hand should be maintained in the position of

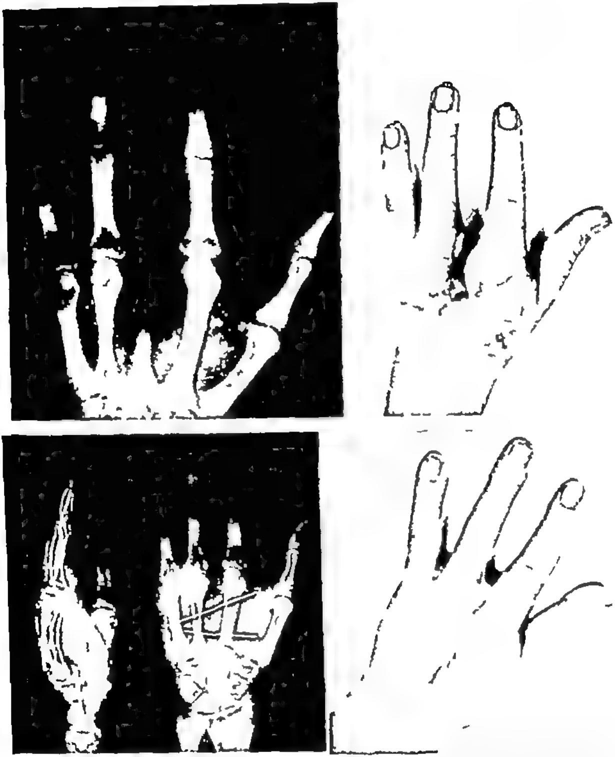


FIG. 222 (*Upper*) Gunshot wound which destroyed most of third metacarpal and surrounding structures, with loss of a finger There was a painful neuroma and stiffening of all finger joints.

(*Lower*) The remains of the third ray with cicatrix and neuroma were excised The marginal, or index finger was jogged over into its place and the hand was narrowed closing the cleft. Later the extensor tendons were freed. A good functioning hand results. (Courtesy of Walter Graham Lt. Col. M C., Valley Forge General Hospital.)

function and the casts should not be kept on too long Gunshot wounds through metacarpals present many problems in reconstruction

Excision of Ray When a hand is badly crippled like that just described, it is better to excise the whole digital ray including metacarpal together with a block excision

Fig. 226 Recession operation for defect of head of metacarpal.
(*Top*) Gunshot wound destroying only head of bone leaving remainder of finger intact.
(*Center*) Recession of proximal phalanx mortising it into stump of metacarpal. Head of phalanx takes its place in the line of metacarpal heads for a firm arch. Proximal joints are all in line.
(*Bottom*) Appearance of hand with one short finger (Courtesy of L. D. Howard, Lt. Col., M.C. Wakeman General Hospital.)

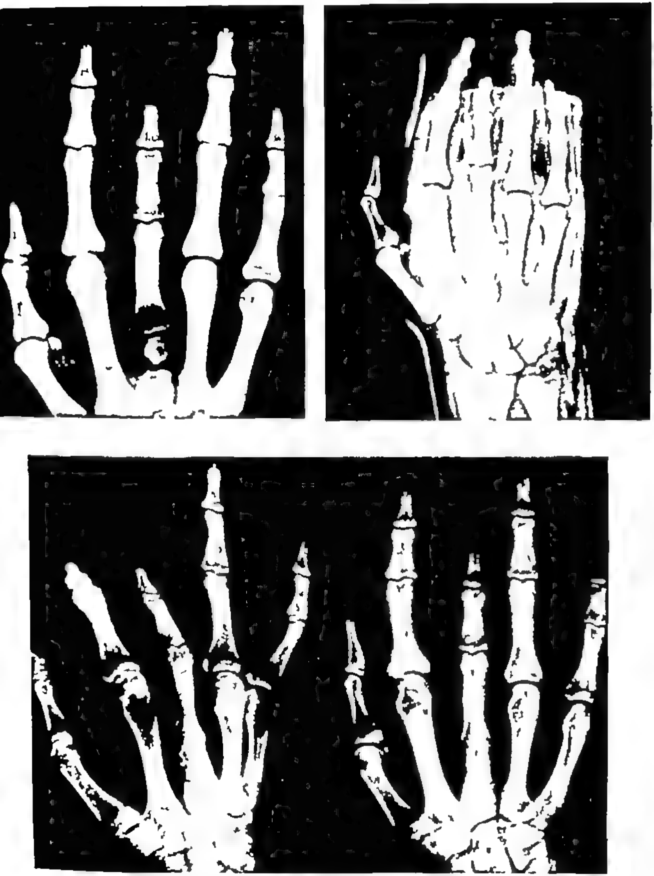
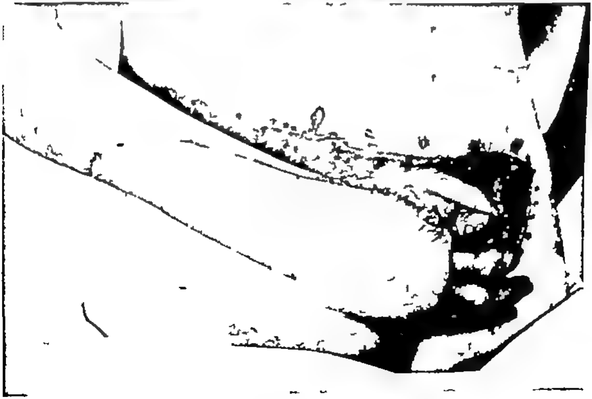


Fig. 227 Recession of proximal phalanx in a case in which the metacarpal had been lost from osteomyelitis in childhood.
(*Upper left*) Preoperative.
(*Upper right*) Bone graft and recession done by Carroll O. Adams, M.D.
(*Lower*) Result three years later. (Courtesy of Carroll O. Adams.)



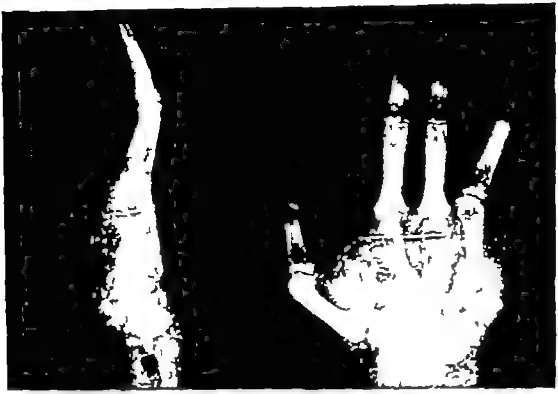


FIG. 228 . Graft of metatarsal to metacarpal and other extensive reconstruction.

(*Opposite page top*) From a dynamite explosion, soft tissues on the dorsum were lost from the proximal finger joints to well up the forearm including extensor tendons, fracturing in a comminuted way the metacarpals and exposing the end of the radius. The index was amputated. The patient was totally blinded.

(*Opposite page bottom*) Cicatrix was replaced by a large abdominal flap

(*Top*) The fifth metatarsal with its head and joint capsule, was grafted into the remains of the second metacarpal. The index finger was amputated. Ten inch to 12 inch tendon grafts of the long extensors of the toes were used to extend the remaining three fingers

(*Bottom*) The repair was over a period of eight months. All proximal joints flexed to 90 the synthetic one to 100 (Pictures were not taken to show this.) The patient gained a very useful hand. (Courtesy of W C. Graham Lt. Col., M C., Valley Forge General Hospital.)

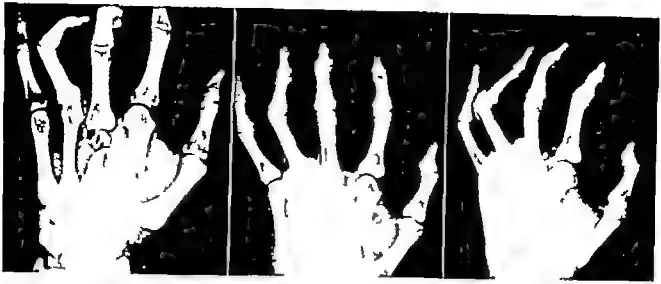


FIG 229 Metatarsal grafted into metacarpal To replace loss of head and neck of the third metacarpal which had been injured by shell fragment, a graft was used from the fifth metatarsal. This consisted of part of shaft, the head the proximal articular surface of the joint, and the joint capsule. Later an extensor tendon graft was placed. The result when last checked (nine months later) was good, smooth motion (Courtesy of W C. Graham, Lt. Col., M.C., Valley Forge General Hospital)

ring If of a central metacarpal, long or ring, the head is missing, the two adjoining fingers will cross on flexion as they are no longer braced against the intervening metacarpal head and so will roll toward each other, tipping the joint axes Therefore, after the shaft is removed the adjoining marginal metacarpal is moved over for this bracing effect of the heads The base of either may be left or the entire ring metacarpal may be removed as no wrist extensor inserts into it.

An alternate method, in case the long or ring finger must be sacrificed, is to recess the proximal phalanx until the middle finger joint is in the place of the metacarpal head and unite the phalanx to the stump of the metacarpal (Adams) L D Howard found that the distal attachment furnishes sufficient circulation to the proximal phalanx Later the surplus skin may be removed The finger will remain shortened to two segments or may be amputated at its middle joint.

Replacement of a metacarpal head by a bone graft constitutes, also, an arthroplasty There has been too much limitation of motion in such cases

A cross bone graft may, in case of loss of a metacarpal head, be thrust into the two adjoining metacarpals to keep them from rotating The phalanx of the finger will

FIG. 230 (*Opposite page*) Transplant of the fifth metatarsal with head and joint ligament to build out the third metacarpal.

(*Top row*) Preoperative condition. Fingers could not flex, as their proximal joints were straight and stiff and the extensor tendons were injured.

(*Center left*) A pedicle skin graft was applied.

(*Center right*) Later a capsulectomy was done in the proximal joint of the ring finger and the extensor tendon of the long finger was repaired by a graft. A new metacarpal was grafted from the fifth metatarsal. As the interossei to the long finger had been destroyed, the sublimis tendon was withdrawn into the palm passed down through the lumbrical canals and sutured to the lateral bands of the long and ring fingers to extend the distal two joints and to maintain flexion in the proximal joints.

(*Bottom*) On discharge the patient had 90 of voluntary motion in the new proximal finger joint (it flexed to 110 passively) and the grafted extensor tendon could extend the joint completely The metatarsal functioned well as a metacarpal. (Courtesy of W C. Graham, Lt. Col., M C., Valley Forge General Hospital.)

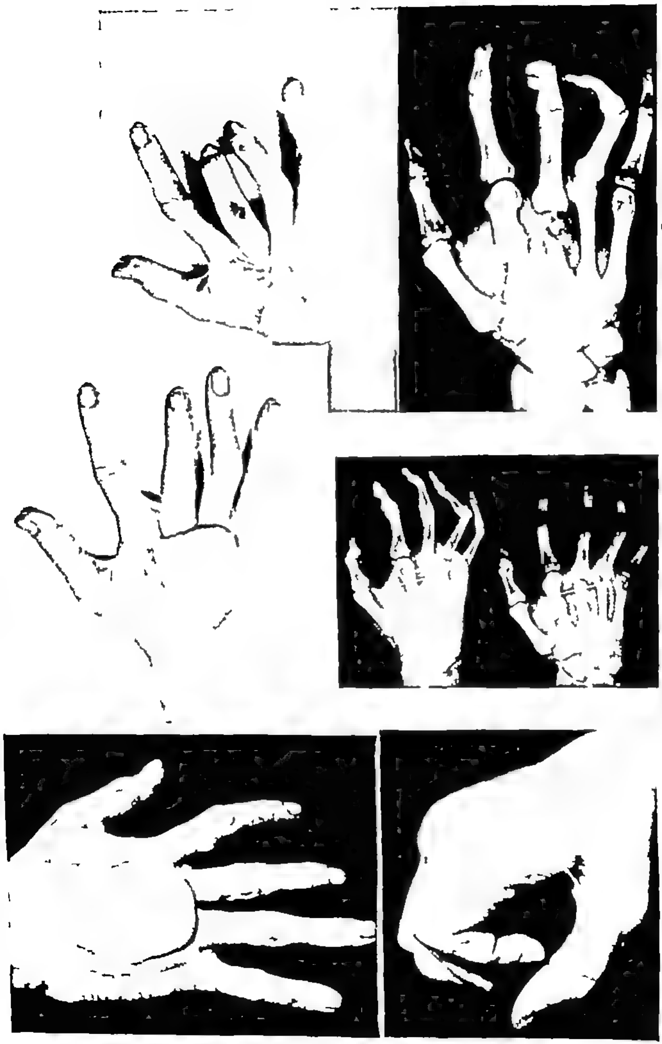


FIG. 230. For legend see opposite page.

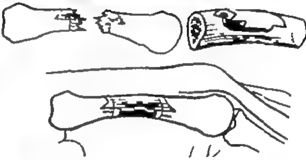


Fig. 231 Defect in metacarpal filled by mortising in a piece of rib.
(*Top*) Defect.
(*Left*) Firm union of graft in five weeks.
(*Right*) Mortise method used. (Courtesy of E. K. Prigge, Col., M.C., DeWitt General Hospital.)

then rest on this crossbar as a poor arthroplasty or preferably the finger is amputated, utilizing its skin. An arthroplasty in which one of the bones is a graft without a covering of articular cartilage results in poor motion and even shortening by absorption.

When surrounding tissues are in good condition, a new metacarpal head may be constructed by a solid graft or by filling in bone chips.

A new head and part of a shaft may be grafted in by taking the fifth metatarsal. It *is removed obliquely at its base to leave the* latter for weight bearing. Also, a phalanx can be similarly used. With the head should be carried enough ligaments to form a new joint capsule. The graft is firmly pinned in place. Such cases followed for eight and six months (Graham and Bunnell) showed smooth joint motion of from 60 to 80 degrees. A complete proximal joint has been grafted several times. Some ended

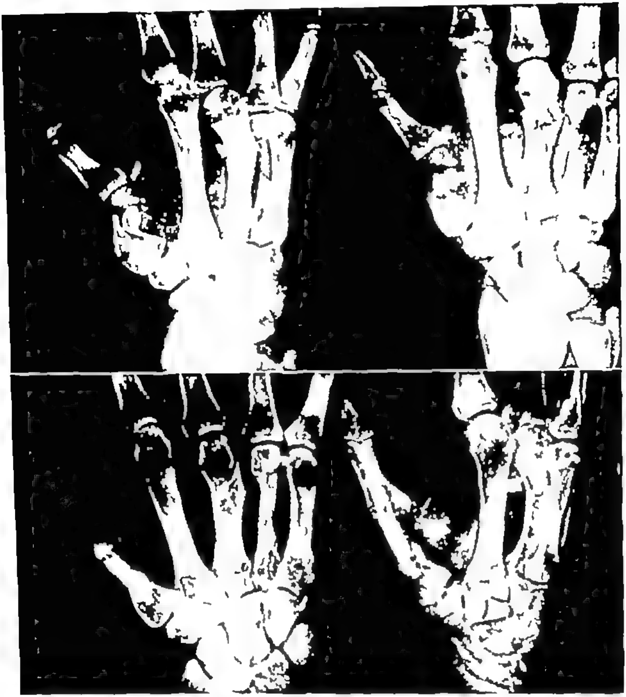


FIG. 232 Repair of metacarpal defects by grafts from rib
(*Upper*) Defect in first and fourth metacarpals.
(*Lower*) Grafts from rib replace the lost bone. That in the thumb metacarpal is impaled into the phalanx. Rib grafts, like iliac unite in metacarpals in five weeks. (Courtesy of E. K. Prigge, Col. M.C., DeWitt General Hospital.)

in ankylosis. Cuthbert s several cases which I saw had good motion at that time.

If there is only partial loss of a meta carpal head there may be left sufficient motion in this irregular joint as a natural arthroplasty, but if motion is limited an arthroplasty is indicated.

Defect of Shaft of Metacarpal If adjoining cicatrix and damage is great, the remainder of the ray may be excised with much improvement in loosening up the hand. By filleting the finger and narrowing the hand, the dorsal cicatrix may be removed If surrounding structures are good, the metacarpal may be reconstructed by a linear bone graft. (See Bone Carpentry) It is not necessary to gain length preoperatively by skeletal traction. It will be found

that after complete excision of surrounding cicatrix, sufficient length is gained. If a graft pointed at each end is inserted in the gap, some of this length will be lost. If, though, one of the points is passed through a notch in the metacarpal head, greater length will be conserved. It is well to have the metacarpal head on a level with the others so that the soft parts will not form a sling preventing flexion when that finger alone is flexed. When all are flexed together such a sling does not interfere An alternative is to place a cross bone graft, joining the necks of the three metacarpal heads

Loss of Base of Metacarpal A linear bone graft is used to replace the defect. It is either rested on or is impaled into the carpus The shaft, if long, may instead be united to the adjoining metacarpal to form a Y metacarpal on which is supported two fingers. This is successful in a marginal ray Two heads may be mounted on one broad bone graft.

Defect of Distal Ends of Both the Second and Third Metacarpals. The shaft of the index metacarpal should be removed diagonally at its base as it will project in the way, but all that is left of the long metacarpal should remain as it is useful as an opposing prominence to the thumb If, then, the thumb does not easily work

FIG. 233 Metatarsal grafted into metacarpal.

(*Left*) This hand held TNT which exploded. The index finger was discarded.

(*Lower*) To replace the MP joint of the long finger the distal part of the fifth metatarsal, together with its head and joint capsule, was grafted in. This was followed by replacement by grafts of the three extensor tendons. A good result was obtained. The MP joint of the long finger moved 70 (Courtesy of W C. Graham, Lt. Col. M.C., Valley Forge General Hospital)

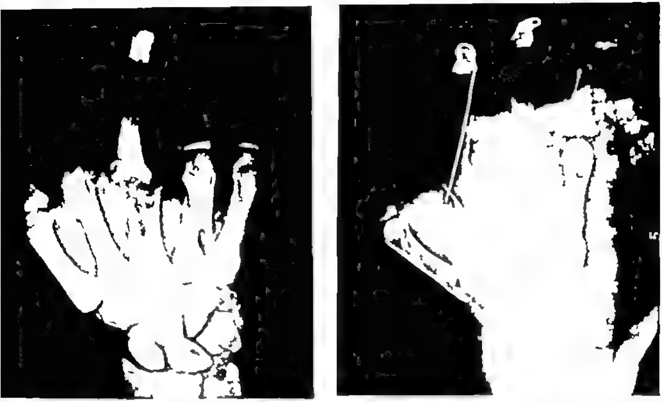
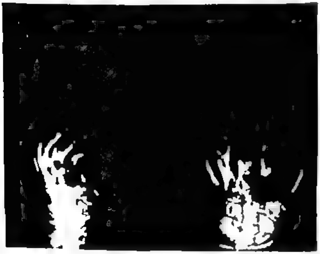


FIG. 234 (*Left*) From shell fragment, the proximal finger joints were destroyed in the index and long fingers. As the index finger was beyond repair its middle joint was grafted into the proximal joint of the long finger

(*Right*) Joint, with part of each bone, is fastened in place with oblique pinning Unfortunately infection occurred. (Courtesy of W C. Graham Lt. Col. M.C., Valley Forge General Hospital.)



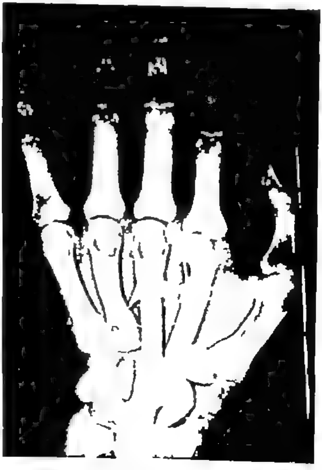


FIG. 235A Gunshot wound through bases of second third and fourth metacarpals.

(*Above*) Preoperative. Cicatrix was first replaced by pedicle skin.

(*Right*) Two grafts from tibia were united in three months. Third metacarpal was straightened. Later extensor tendons were freed and capsulectomy was done to the knuckles (Courtesy of James W Littler Major M C Cushing General Hospital.)

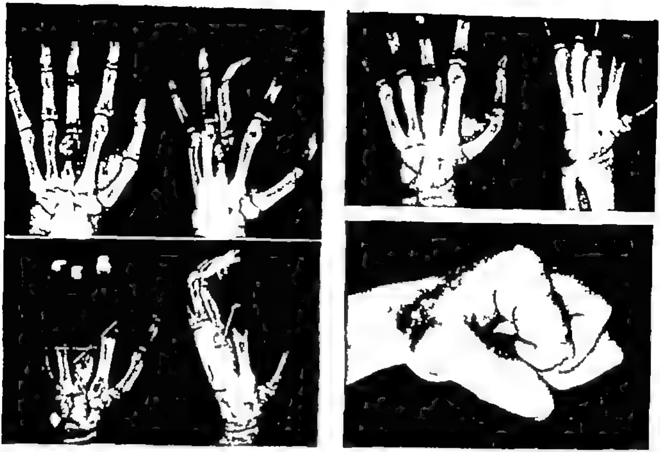


FIG. 235B Iliac bone pinned in place to fill defect in metacarpal shaft. (*Upper left*) Defect. (*Lower left*) Broad graft may be pinned in any direction. (*Upper right*) Union is firm in five weeks compared with eight to ten weeks with cortical bone (*Lower right*) Flexion of proximal finger joints is increasing. If bone is pinned firmly capsulectomy may be done at same time. (Courtesy of L D Howard Lt. Col. M C., Wakeman General Hospital.)

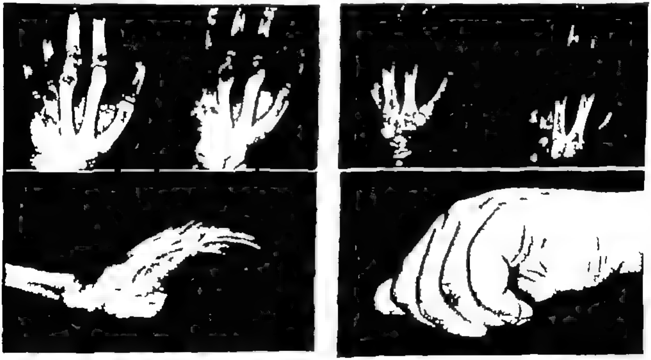


FIG. 236 Use of iliac bone for graft in metacarpal Unites in five weeks. Easily pinned. (*Upper left*) Defect with shortening of two metacarpals. (*Lower left and upper right*) Defects filled showing longitudinal pinning. (*Lower right*) Shows degree of flexion gained by capsulectomy of MP joints at time of bone graft. (Courtesy of L. D Howard, Lt. Col., M.C., Wakeman General Hospital.)

FIG. 237 Defect in shaft of metacarpal filled by insetting graft of cortical bone. (Courtesy of George Phalen Lt. Col., M C. O'Reilly General Hospital.)

FIG. 238 (*Right*) (A) Loss, from gun shot wound, of bases of the first three metacarpals and adjoining part of carpus. Soft parts were in good condition.

(B) Metacarpals were reconstructed with three tibial grafts restoring good length, the metacarpal arch and good position of the thumb (Courtesy of James W Littler Major M.C., Cushing General Hospital.)

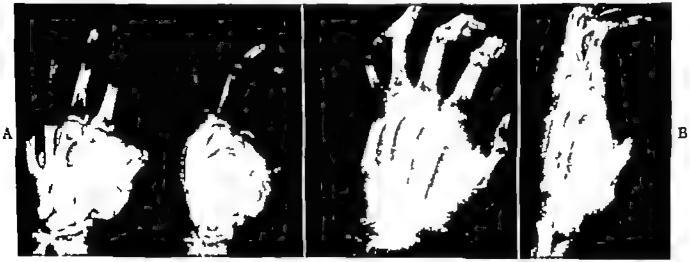


FIG. 239 (A) Shell fragment destroyed extensively the first metacarpal most of the second and the proximal part of the third. Nerve and flexor tendons were intact. The extensors were later repaired. A large abdominal pedicle was applied to the dorsum allowing enough to advance the thumb

(B) Tibial bone grafts restored metacarpals with good length that to thumb is fused to carpus and proximal phalanx. To insure correct position for thumb the tips of the first three digits were sutured together Good union resulted in three months. (Courtesy of James W Littler Major M.C. Cushing General Hospital.)

A

FIG. 240 (A) Shell fragment caused complete loss of the last three metacarpals (B) Third ray the most cicatricial, was removed to loosen the hand by narrowing it, and the finger was filleted and used to cover the dorsum. Stability was furnished to the ring and little fingers by a flat iliac bone graft, joining their proximal phalanges to the carpus. The extensor tendons were repaired.

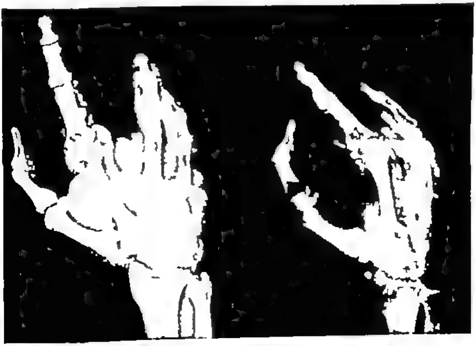
against the ring and little fingers, a rotary angulatory osteotomy at the base of its metacarpal will relieve the strain.

After metacarpal injury the proximal finger joint will be stiff and straight. Whenever it is possible to make a firm enough reconstruction of a metacarpal, capsulectomy should be done at the same time. If the bone reconstruction is not stable and firm, the strain of flexing the joint will throw it out of alignment.

Loss of Bony Alignment. To reëstablish correct mechanics and muscle balance the bony framework must be realigned to the normal Bowed or dislocated metacarpals must be straightened and dislocations about the carpus must be corrected. The latter is done through the dorsum by liberally excising the cicatrix about the dislocation, excavating a space to receive the dislocated bone and pinning it in place with a subcutaneous, removable Kirschner wire. If the thumb metacarpal or the adjoining part of the carpus is dislocated backwards the thumb assumes a position close to the hand with the first two metacarpals parallel Here the base of the metacarpal must be repositioned for proper mechanics.

The metacarpal problem whether from

B



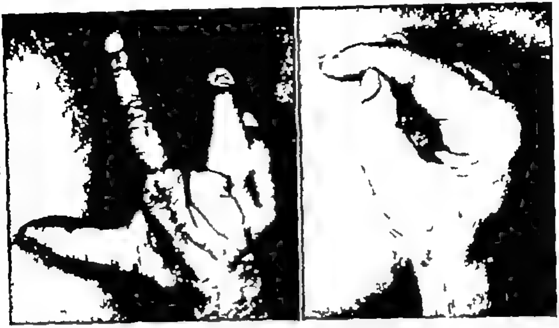


FIG. 240 (C and D) A useful hand was obtained. (Operation at Bushnell General Hospital by S Bunnell and Harold W Woughter Lt. Col M C)

gunshot wound or not, comprises more than just the repair of the metacarpals. Usually the long extensors of the fingers are densely adherent to the bone and the proximal finger joints are stiff and straight. These two complications may be corrected at the same operation at which the metacarpal is repaired providing that the fracture is not too close to the head of the metacarpal Thus the extensor tendons may be freed and gliding material placed between them and the bone, and capsulectomies may be done The latter requires firm fixation of the metacarpal repair so that displacement will not occur, and flexion of the proximal finger joints must be maintained postoperatively by rubber bands Frequently in such a case the skin on the dorsum is insufficient to allow flexion of the proximal finger joints In this case the skin is incised transversely the edges allowed to gap and immediate cover supplied by a free skin graft. This will take successfully as the capsulectomy is done from inside the aponeurotic hood

Osteotomy of Metacarpals for Claw hand. In extreme clawhand from old ulnar palsy or flexion contracture which cannot be adequately corrected by operations on the ligaments Steindler claims good results from osteotomy of the necks of the metacarpals in order to tip these volarward in compensation for the dorsiflexion of the proximal finger joints In some extreme cases he has even resected parts of the metacarpals. When the claw deformity is due to extensive cicatrix, as from burn, the joints may be relaxed enough for some useful motion by resecting either the bases of the proximal phalanges, heads of the metacarpals, or as in Hudack's case, the bases of the metacarpals

TRAUMATIC DEGENERATION OF CARPAL BONES

This condition was first described by Preiser for the navicular bone in 1910, and later in the same year by Kienböck

Many investigators became interested in this condition and wrote of it under the following names traumatic rarefying osteitis, traumatic malacia, traumatic nutritional disturbance, osteodystrophia cystica, localized osteitis fibrosa, necrosis, chronic osteitis softening, traumatic atrophy, and localized osteoporosis.

Incidence The condition occurs commonly in the lunate one-fifth as often in the navicular and rarely in the capitate or

A B C

FIG. 241 Destruction by shell fragment of most of the first metacarpal, base of second and the multangular bone. The free floating thumb is useless. (A) Preoperative. (B and C) After the scar was excised and replaced by pedicle skin, the first two metacarpals were united to the carpus by a graft from the tibia in correct position. A new extensor pollicis longus tendon was *grafted in using the palmaris longus.* (D and E) Excellent functional result. (Courtesy of James W Littler Major M.C. Cushing General Hospital.)

D E

hamate It is three or four times more frequent in males, and is seen in the right hand about three times more often than in the left. It occurs principally in manual workers between the ages of 20 and 50, particularly in those in the thirties.

Etiology The usual history is that of a fall on the dorsiflexed hand. Some patients tell of trivial or repeated injuries, and others do not recall having sustained an injury In many cases the fracture line can be demonstrated through the lunate bone. Sometimes this line is quite fine, and it is necessary to take roentgen pictures in various directions to find it. If the condition results from tearing off of the blood supply from the lunate, we should expect to find it as a late result of all dislocations

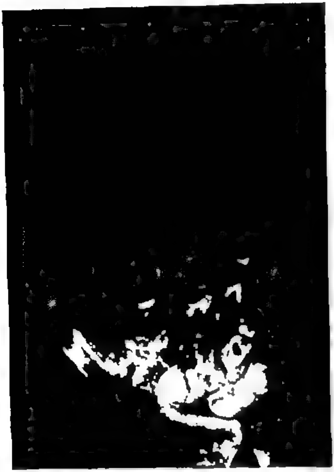
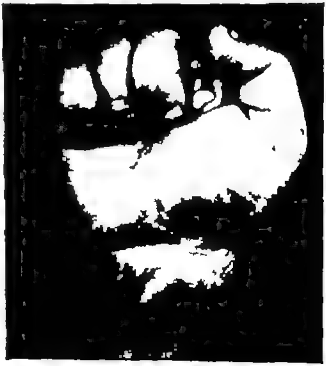


FIG. 242 (A, *Left*, B *Right*, C, *Below*) Treatment overseas by direct flap hand healed after arrival at home. In spite of x ray appearance, no surgery was done because of good function and the absence of pain. (Courtesy of L. D Howard, Lt. Col., M C. Wakeman General Hospital.)



of this bone, but this is far from the case. We do know that the semilunar bone is very subject to strains of compression. In a fall on the dorsiflexed hand it is directly between the head of the capitate bone and the radius. This direction of force is verified by the shape of the bone in late cases after crushing has occurred. It seems quite probable that such a compression trauma, either with or without fracture, can precipitate this traumatic degeneration The condition can hardly be classed with Osgood Schlatter's, Legg-Calvé-Perthes', and Köhler's disease, because these are all associated with the period of growth of the respective bones instead of with middle age.

Various untenable theories for the cause of the progressive degeneration have been advanced such as embolism, infection, direct pressure, or loss of blood supply Of these the latter, though inadequate of explanation, is more probable but it does not explain the increased vascularity and the osteoporosis commonly seen in early cases

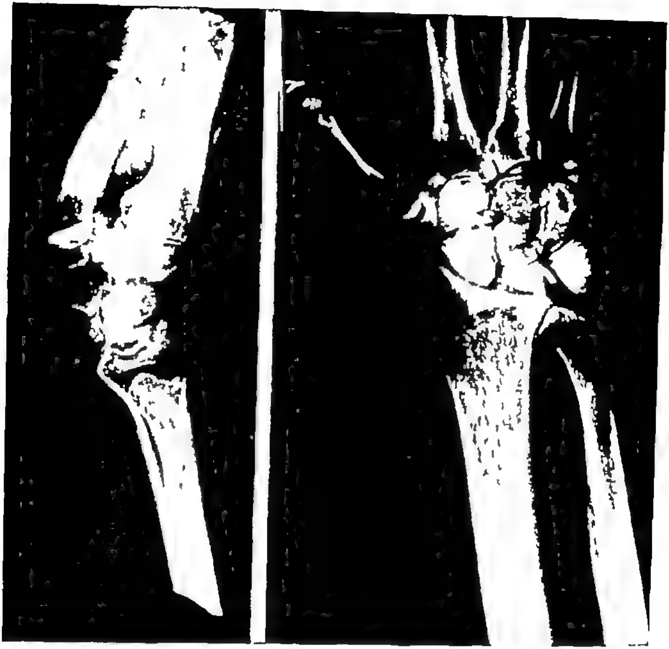


Fig. 248 Case D A., aged 25 Kienböck's disease.
(A and B) Three years previously he forcefully struck his left hand, injuring the lunate. The wrist is now too sore, painful, and lame to work. X ray views show the lunate to be degenerated, crushed, and open to the joint, where there is much arthritis. Navicular is tipped not fractured. Lunate should be removed to check arthritis.

prove to be a vascular area. The whole bone becomes slightly enlarged, as compared with the other, but eventually it shortens and widens, and finally it may crush between the head of the capitate and the radius and spread out widely in the joint. *If a fracture line is present, it is* probably the result of the original compressive force but in some cases may be secondary

Microscopic sections of the bone, removed after the condition has been established, show patchy aseptic necrosis accompanied by evidence of regeneration The trabeculae are fragmented in disorderly manner, and there is fibrous replacement of bone. *Connective tissue proliferates in the* marrow, and at the same time there is osseous metaplasia. The vessels are hypertrophied, showing increased vascularity

FIG. 249A. Kienböck's disease of lunate, showing narrow fracture line and increased density

FIG. 249B Late Kienböck's disease of the lunate, with considerable arthritis and disability

The cartilage of the articular surfaces shows secondary erosion over the areas of greatest necrosis. This is usually where they press on the radius and similar erosion may be seen on the articular surfaces of the adjoining bones, together with other signs of arthritis at the ligamentous attachments. This arthritis is regularly seen roentgenographically, and it becomes greatest in late cases in which the mechanics of the wrist joint have been upset by the lunate's being crushed out of shape Arthritis in the early cases occurs in response to tissue reaction in the parts contiguous to the affected bone where the process of necrosis and replacement is going on.

Symptoms. The initial symptoms are pain, tenderness swelling and limitation of motion—especially on dorsiflexion of the wrist. The pain is through the wrist and radiates up the forearm, the tenderness is local over both the dorsal and volar surfaces of either the lunate or the navicular bone. There is some general swelling of the wrist, but the edema is specially localized over the affected bone, as can be recognized by pinching up a fold of skin These symptoms may appear immediately following trauma or gradually thereafter They may persist for a few days to several weeks and then usually subside for a varying interval of weeks to years, after which the symptoms of the established condition increase and are progressive, causing considerable disability In addition to the symptoms above mentioned, pain is produced by shoving up the finger rays which makes pressure on the affected bone—especially in the case of the lunate, the long finger, and for the scaphoid the index and thumb The roentgen appearance establishes the diagnosis. Some cases entirely recover, others have recurrence in spells. Many however, show prolonged disability, even up to 20 years. By that time there is, of course, marked hypertrophic arthritis which makes the disability permanent.

Treatment. Considering that in many instances a cure is brought about by conservative treatment in a cast for six to eight months and that this usually brings at least temporary improvement, conservative treatment should be given a trial. A nonpadded

cast is applied to the hand and forearm, stopping at both the thenar and the distal creases in the palm to allow full motion of the digits. Successful treatment by drilling the bone has been reported. It is based on allowing the necrotic products to escape and bringing in a new blood supply The usual treatment is to excise either the lunate or the navicular as soon as the condition has proved to be increasing or permanent. The sooner this is done, the less will be the resulting hypertrophic arthritis. Once the latter is established it is largely permanent Following excision of the lunate bone there will be a certain amount of lameness and soreness of the wrist which will eventually disappear, though many will complain of some pain on prolonged use or overwork. Most cases show some diminution of grip The same must be said following the removal of the navicular bone. In some cases the disability will not be noticed, and in others a certain amount of lameness will follow There will be less complaint from the nonmanual workers.

Klutchareva reports some good results from merely scooping out the necrotic area and leaving the good bone.

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7

Joints

The problem of stiff joints is greater in the hand than in any other part of the body The finger joints stiffen on slight provocation and as the natural sequel or consequence of most of the ailments of the hand Much of this stiffening, however, can, by the proper treatment, be prevented. The tendency to stiffen, though greater in the aged, varies greatly in individuals. In some the tendency is manifested by hypertrophic arthritis or Dupuytren s contracture, but in many it is impossible to foretell that they will have an overgrowth of contracting fibrous tissue. This same tendency shows itself through all of their tissues, including joints, tendons, muscles, and even the peritoneum in forming adhesions

The nerves have much to do in keeping joints in good condition. When their supply is cut off from the hand degenerative trophic changes occur in all of the tissues from skin to joint, resulting in thinning of the cartilages, porosis in the bones, loss of elasticity and mobility in the ligaments, general shrinkage, and loss of motion An irritative nerve lesion, such as in causalgia, has an even greater effect on the bones and joints. All nutritional changes accelerate any pathologic condition in the joints From vasomotor or sympathetic imbalance many hands show diffuse swelling, osteoporosis, atrophy and stiffening in joints. When, in addition to brachial plexus injury there is also injury of the main artery the hand becomes a stiff cyanotic claw

WHY FINGER JOINTS STIFFEN

A hand, though tough, is made up of many movable mechanical parts of refinement which are fitted together with great accuracy The synovial membranes and the joint capsules and ligaments are supple enough to form folds when relaxed and just long enough to allow full motion of the joint. They hold the joint surfaces snugly together, not allowing any abnormal mobility Whatever alters the dimensions and consistency of these tissues or mechanical parts of the joints limits motion. This, of course, applies also to tendons, tendon sheaths, paratenon, muscles, and other tissues that make up the moving parts of the hand.

Especially vulnerable in a finger joint is the relation between the length of the collateral ligaments to the curve of the joint surface, as particularly exemplified in the metacarpophalangeal joint. When this joint is in extension, the two lateral bands spanning from metacarpal to phalanx in an anterovolar oblique direction, known as collateral ligaments, are relaxed. As the joint flexes, the phalanx sliding around the particular curve of the ever-broadening head of the metacarpal the collateral ligaments become so taut that no lateral movement is permitted. The joint surface of the metacarpal head lessens in curvature volarward and the tubercle of attachment of the collateral ligament is located dorsally There

fore, the distance the collateral ligament must reach when the joint is flexed is 2 mm greater than when it is extended. Whatever then, as soon to be pointed out, shortens the collateral ligament will make it impossible for the phalanx to reach around the bend of the metacarpal joint surface and so will prevent flexion Stiffening of the proximal finger joint in the straight position is the most common and troublesome complication of hand injuries

When a hand remains swollen, from whatever cause, the movable parts are bathed in serofibrinous exudate. This deposits fibrin between the various tissue layers and in the folds of the joint capsules, between the tendons and their sheaths, throughout the ligamentous tissue itself, and between and within the muscles While soaked in the exudate all these tissues swell with edema and become shorter and thicker The fibrin seals them in this condition, and soon, as the fibroblastic growth transforms all to connective tissue, the ligaments become fixedly shorter and thicker The folds of synovial membrane, the capsules of joints, the plicae of tendon sheaths and the tendons and their sheaths become plastered together with organized adhesions

Swelling from edema with this serofibrinous exudate may come from many causes, it may follow general traumatism to the hand or even an injury of the arm. It regularly accompanies fractures in the hand and also in the forearm, and even in the upper arm. Injured joints like fractures cause swelling—especially if not immobilized. Splinting a joint on a strain injures and stiffens it. Hematoma or general ecchymosis of the tissues causes edematous swelling, but the outstanding cause is infection Functional disuse of the hand may in itself cause edema. The tissue fluids stagnate from the lack of pumping by muscle action and the waste products from general stasis complete the setting for a large swollen hand Stagnant fluids stiffen intensely as is seen in injuries of the arm where the main vessels are interrupted, rendering the hand cyanotic.

Thus, edema is pernicious and may come from many causes Edema alone may not cause a hand to stiffen, but when it is accompanied by immobilization so that the tissues are allowed to set in that condition, stiffening is inevitable The hand may require months or years to recover motion or the disability may be permanent.

PREVENTING JOINTS FROM STIFFENING

To prevent stiffening we should lessen the edema and keep the injured parts actively moving

Decrease Edema. The part should at first, and as long as necessary, be elevated, keeping the hand the highest, so by gravity the fluid will run out. Elastic bandaging helps

A fracture should be completely immobilized by splinting, including one joint above and one below, preferably by the nonpadded cast, as motion at the fracture site causes reactive swelling

Complete immobility by the nonpadded cast stops pain. Pain, reflexly, causes disuse, edema, and stiffening of joints.

During the healing of fractures massage and manipulation should be strictly avoided, as they cause edema and reactive overhealing Too strenuous exercises following healing should not be taken because they traumatize tissue.

Keep Uninjured Parts Actively Moving All parts that are not injured should be kept unrestrained and free to move—especially if contiguous to the injury The limb as a whole should be kept in use if possible. This is the functional treatment of fractures, so ably described by Böhler and Watson Jones Action of the muscles pumps the tissue fluids through the limb, preventing edema, stagnation, and stasis, and keeps the tissues nourished and activated If a cast is applied to a forearm

and hand for a fracture of the forearm, such as a Colles', it should end at the distal crease in the palm, for free and complete movement of the fingers, and at the thenar crease for unhampered movement of the thumb The patient should be compelled to move the digits, commencing at once and through the full range. Though this pains at first, the pain leaves in a few days if the motion is continued If one finger is splinted, the others cannot move voluntarily through full range because of the interdigitation of tendons and because they have a common muscle, but they can move passively, and the cast should be limited to allow it Exercise should be kept up intermittently all day and every day The hand and arm should be used in the daily work, such as sweeping, and for women making beds In moving the digits, the tendons work freely through the wrist and the pumping of the muscles in the forearm keeps away edema and stasis.

On removal of a cast after functional treatment usually half range of motion is possible at once and complete motion soon If, though, the cast has been extended to include the fingers in part or whole, the hand—in the short time of five weeks of edema plus immobilization—will be painful and stiff throughout, sometimes terminating in permanent limitation of motion Casts should stop at the distal crease in the palm for free finger motion and at the thenar crease for opposition of the thumb Errors that stiffen joints are making casts that are too long enclosing fingers, splinting all fingers instead of just the injured one, making casts in positions of nonfunction and leaving them on too long A recent example was a man whose hand was totally stiff in typical position of nonfunction. The hand had not been injured, but because of a fractured humerus the cast had been applied to as far as the ends of the fingers and left on for three months

It is incumbent upon the surgeon to prevent stiffening of the hand for if left to himself the patient will, because of discomfort, refrain from moving his hand. The surgeon should explain to him what the resulting edema and immobilization will entail, and should follow through to see that this is prevented The surgeon should be on the alert to recognize early cases that will later go on to an edematous, immobile, osteoporotic hand by recognizing signs of trophic disturbance and the disposition on the part of the patient to hold his hand completely immobile Such cases are only an exaggeration of the normal, and if the condition is not prevented early, even years of treatment afterward may be of no avail

Wounds should be closed promptly after injury If they are left open for one or two months, the absorption of products of inflammation causes edema and stiffening of joints and other tissues A hand promptly closed and exercised remains supple. All pedicles to the hand should be closed, not raw (i.e., septic), or they cause stiffening just as do open wounds

Following infections, as soon as the acuteness has subsided motion of the digits should be started and persisted in, so as to ward off early the otherwise inevitable stiffness.

During healing from infection or injury a surgeon must not neglect to maintain the joints in positions of function This precaution will greatly shorten the period of rehabilitation and will give a better limb

If, after injury or infection, the proximal finger joints are allowed to remain straight, they will stiffen so If, however, they are kept flexed they will always be able to extend as the lengths of their collateral ligaments will have been maintained To be convinced of this, compare the lateral play in one's own joint when straight and when flexed. Whenever possible splinting should be of the elastic type rather than rigid as this keeps joints exercised and free

In all cases of injured hands the patient should be instructed not to keep his arm at his side with the forearm across his chest,

otherwise, in two months it will be found that the arm at the shoulder can neither be raised nor externally rotated The correction of this condition is described in Chapter 11, The Arm in Its Relation to the Hand

MOBILIZING STIFFENED JOINTS

Before repairing tendons joints must first be placed in good position and have a good range of motion.

In all longstanding flexion contractures all tissues including the ligaments of the joints share in the contracture, so that even when all other restraining tissues are severed the joint ligaments will still keep the joint from extending Severance, excision, or elongation of these ligaments by slow traction will be necessary

Place in Position of Function. A patient coming *for repair following extensive* hand injury or severe infection usually has great limitation of motion of his joints, and in addition the joints are in position of non *function. It is probable that the wrist will* be in flexion, the carpal and metacarpal arches flat, and the thumb at the side of the hand. The proximal finger joints may be straight or hyperextended and the distal two joints of the fingers slightly flexed. Such a hand is useless, and any motion of the digits that it may have will be of no avail, as the thumb and fingers cannot approximate each other First joints are drawn *into the positions of function fol* lowed by use of the hand in occupational therapy If this is not done, capsulectomy may be necessary especially in the proximal finger joints. If the joints, as shown by x ray, are in poor condition, arthroplasty or arthrodesis is in order Our first procedure should be gradually to bend these joints around until each is in the position of func*tion that is with the wrist in dorsiflexion* of about 30° the carpal and metacarpal arches well curved, the thumb in the position of opposition, and the finger joints in flexion. In these positions if the fingers and thumb show only one half inch of motion this motion will be useful, while in the position of nonfunction the patient will refrain from using his hand at all and even disconnect it from his mind. Since the position of function allows him to pick *up small objects, he will commence to use* his hand. Under the stimulus of this function its motion will increase and he will use it more, so that a happy circle will be established which will lead to greater function. (Chap 4, Fig 61)

Gaining and maintaining the position of function should ever be our goal throughout hand surgery At this position there is the greatest function It is the starting point of all motions and here the mechanics are most efficient. The position should be maintained throughout our treatment for infections and the results of trauma.

Continuous Mild Traction. If flexion contracture is present from superficial or deep cicatrix, it should first be corrected by plastic procedures. The use of continuous mild traction to bend joints around to a better position or to gain more motion of flexion or extension differs greatly in results from the intermittent bending of joints, or the so-called pump-handle method. *Intermittent force applied to the straining* ligaments merely stretches them, and like the rubber band these ligaments will immediately shorten again In addition there will be tiny tears and hemorrhages which will be followed by tissue reaction, *resulting* in further cicatricial contraction.

By the continuous mild traction method however, a slight stretch is maintained on the restraining tissues until by cell multiplication they actually grow longer and therefore, the lengthening will be permanent. The yielding of tissues to continuous mild force, together with adaptation by growth to the new position is exemplified in the straightening of teeth by the orthodontist or in the extreme deformities seen

Fig. 250A (*Top*) Preoperative position of nonfunction from shark bite in upper arm severing nerves and vessels. (*Bottom*) Correction to position of function postoperatively by fusion of wrist capsulectomies, opening of cleft of thumb a pulley tendon transfer for opposition and transferring extensors of wrist to flexors of fingers.

Fig. 250B (*Right*) Old dislocation of metacarpals on carpus upsetting the muscle balance, thus resulting in useless position of nonfunction. (*Bottom*) Dislocation reduced restoring muscle balance in the position of function Pedicle graft was applied to dorsum of hand and to opened thumb cleft Freeing of extensor tendons and capsulectomies allowed proximal finger joints to flex.

gation of tissues to make way for tremendous tumor growths. The orthodontist uses two principles. One, continuous spring tension and, two, intermittent bevel action pressure in biting. The continuous mild traction to correct the deformity in the joint is applied to the limb by well padded splints. This traction to bend joints should be maintained continuously throughout the 24 hours, but it should be intermittently released every hour or two by day, so that for short intervals the joints can be exercised to prevent stiffening. If traction is maintained for too many weeks, joints will stiffen. Anything that ties up a hand too long has a tendency to stiffen it. Traction should be fairly gentle, yet firm enough to yield results. If it is too forceful there will be pain, swelling, and damage to the joint, including pressure atrophy of the articular cartilages. The skin pressed on should be watched for effects of ischemia, the first sign being a brownish color.

Continuous traction should be applied by plaster casts with intermittent wedging, by metal splints with web belts and buckles or by elastic or spring splinting. Casts are positive, and a patient intolerable of apparatus is less apt to remove them. They work well in growing limbs for clubfeet or clinarthrosis but less so in injuries from trauma in adults as they cause stiffness. When using metal splints, each day the web belt and buckle is tightened or the splint is given a little more bend. This works well, but if persisted in too long causes stiffening. Best results are obtained by elastic or spring traction, using rubber bands, spring wire or flat spring steel.

Elastic or spring splinting for this excels as the joint is protected from overstress and can be moved continuously thus preventing stiffening. Elastic traction actually serves to exercise and mobilize a hand. The play of muscles and movable parts disseminates the stagnant fluids allowing the tissues to return to normal. Elastic splinting is physiologic and effective. (P. 112.) In the case of very stubborn joints, all that can be accomplished is to bend them into a position of function so that their limited range of motion will then be useful, or if ankylosis is the eventual result the joint will at least be in the right position.

When a joint pains at its limit of flexion it may often be cured by gradually drawing the joint into complete flexion. If maintained so for two weeks, until the restraining tissues elongate, the joint will then flex without pain.

SPECIAL SPLINTS. To force the wrist into dorsiflexion a cock up splint is used, gradually tightening the strap over the dorsum of the wrist. As the wrist bends back the neck of the splint must be bent, so there will always be a space between the wrist and the splint into which the wrist can be drawn. In moderate dorsiflexion, the oblique strap running from the neck of the splint to the dorsum of the wrist is essential to keep this splint from displacing distalward. The best cock up splint for this purpose is one with a spring neckpiece. This may be of either a long loop of spring wire or a ribbon of spring steel.

To draw flexed fingers and wrist into extension, as when the flexor muscles and tendons are too short, a combination of wrist cock up splint and finger splint is used.

The fingers are first straightened by flexing their proximal joints and fastening them between two padded flat pieces of sheet metal. A long arm preferably of spring steel projects proximally from the top piece. This lever arm is then, by web belt and buckle or elastic gradually drawn down to the dorsum of the forearm, thus aided by the cock up splint drawing the wrist and all joints distal to it into extension.

To extend flexed fingers a plaster slab is laid on the dorsum of the forearm and hand and made to extend over the row of proximal finger joints; a layer of felt is placed over the latter. From this plaster extends an outrigger wire over which run rubber bands

that by leather loops draw the fingers into extension. An alternate method is by a ribbon of spring steel, looped around the distal end of the finger and placed over a strip of felt along the dorsum of finger and hand as in Fig 96I. It is fastened by a wrist cord and an adhesive band about the finger

To draw the proximal finger joints into flexion is the most common need. Several principles have been used.

A. Flexion may be started by the meta carpal splint (Fig 92) and finished by the glove traction drawing the finger tips by rubber bands to the wrist band Method C is preferable to this

B A volar plaster slab holds the forearm and hand with the wrist dorsiflexed Em bedded in the plaster an outrigger of wire extends in such a position that rubber bands from the belly of the splint running over the outrigger to leather loops over the proximal finger segments will draw the proximal joints into flexion. The direction of pull is at first at a right angle to the palm but as the joints flex it should gradually become proximalward. To accomplish this the wire outrigger is successively bent. In full flexion the rubber bands may be attached to a hook on a wristlet. A metal cock-up splint may be used instead of the plaster and the malleable metal outrigger may be attached to its forearm piece (Figs 96D and E) Nachlas, who demonstrated this direction of pull made a splint with a sliding outrigger and Luckey, one with an outrigger detachable for three set positions

C The 'knuckle bender" (Fig 96A) of wire and rubber bands is quite efficient small leaves the wrist free as it fits on the hand alone carries the motion through and allows constant exercise. An Oppenheimer splint is attached to dorsiflex the wrist.

Flexion of the middle or distal finger joints can be brought about by a web belt and buckle wrapped about the finger, hand, and wrist, so as to flex these joints (see Fig 92) or by broad rubber bands worn about one or more fingers and the hand.

The thumb can be drawn into opposition and the arches of the hand curved by the simple method of using an adhesive strap looped around the dorsum of the meta carpophalangeal joint. One arm of the strap is then wrapped around the ulnar border of the hand and the other the ulnar border of the forearm, so as to draw the thumb toward the pisiform bone As an alternative, the opposition attachment to the "knuckle bender' splint can be used. To bring about adduction or abduction of the wrist it is necessary to use a form fitting plaster cast, wedged or hinged and with spring or elastic traction Supination can be brought about by fitting a band of metal or plaster around the hand at the palm Rubber bands from each end of this to extensions to a right angled elbow splint rotate the forearm into supination

Various splints are described in Chapter 4, under Splints.

Exercising Stiff Joints. While and after joints are being brought into positions of function, they should be exercised Voluntary exercise and use of the hand by the patient throughout the whole day is far superior in result to the usual thermal and light treatments and forceful passive motion customarily applied only one hour a day Daily forcing of finger joints causes reactive pain and swelling as protoplasm is irritable to trauma The joints become stiffer than ever It is equivalent to spraining them daily and ruins the finger joints Such unphysiologic treatment seems based on early impressions with inanimate objects that forced movements will mobilize a rusty hinge or a stiff piece of leather The patient will not hurt himself, his nerves are his protection against overstraining the joints Before and while the hand is being exercised considerable can be gained by heat, preferably by immersing the hand in moderately hot water Soap added to the water is beneficial in that it allows one hand to be massaged and worked by the other Washing dishes is of advantage. The patient may keep on the hot radiator a bag of sand,

in which the hand can be exercised by clutching the warm sand. Because in time this wears down the pulps, rice or pearl barley (unheated) is preferable A flat block of wood, one-half inch thick with rounded edges, a rubber sponge, or a ball kept in the pocket is handy for exercising the joints. One can exercise to gain pronation and supination by rotating the forearm back and forth with a broomstick or dumbbell in the hand. There is something about the natural use of a hand in light work that is the most conducive to return of joint motion. There is, however, a necessary time factor, for even with the best of treatment a certain interval must elapse before the joints become mobile.

Passive physiotherapy if gentle may be beneficial for only two or three weeks. In nerve lesions it is necessary in order to keep position of the hand and mobility and circulation of the joints and tissues For these cases it must be used over long periods. The patient himself should be instructed to carry out the motions of his paralyzed hand with his other hand Rehabilitation of hands is best done by occupational therapy as described at the end of this chapter and which has advanced so far in our Army hospitals in World War II

When a joint is infected or injured it requires rest. One must judge carefully just when to change to gradual exercise, lest the latter cause a flare-up of the inflammation. Sometimes part of the swollen hand is so tender that a patient will not use any of the hand. A cast which immobilizes just that part, such as the wrist will then allow the digits to be exercised without pain and so improve the whole hand

Brisement Forcé. Forcing stiff fingers under anesthesia is dangerous and usually does harm It not only stiffens the joint the more, but so traumatizes it that it will never recover Also, by this method an osteoporotic bone is easily broken. Only in very exceptional cases will the method be of advantage. If latent infection is still in the joint, as indicated by pain swelling and tenderness, forcing the joint will cause an inflammatory flare up It is only when some particular adhesion is holding back the motion that the method succeeds If on bending the joint, of course, with mild force, a single snap is heard there is chance of success, but if a general tear or yielding of the ligaments about the joint occurs it is probable that increased stiffening will result

SURGICAL REPAIR OF JOINTS

In repairing joints surgically we endeavor to place them in a better position by means of manipulation, freeing of the restraining ligaments and osteotomy Loose joints are stabilized by grafting to them new ligaments and their motion is increased by capsulectomy or arthroplasty Also, joints are rendered solid, painless, and in the correct position by arthrodesis

Caution is essential, lest we operate on a joint in which the inflammatory process still lingers, whether rheumatic, pyogenic or tuberculous, the last is never safe. Pain, tenderness, redness, edema, and the involvement of other joints are warnings that surgery may cause inflammatory flare-up, just as earlier we had to choose in treatment between rest and active motion

The function of joints with intra articular pathology, including degeneration of articular cartilages, adhesions between the bones and destruction of synovia, is not improved by surgery except arthrodesis or arthroplasty Much improvement can be gained, however, when the pathology is extra-articular, as these joints, which in themselves are fairly normal, tolerate surgery Roentgen films are a helpful guide to the condition of the joint.

In all deformed hands coming for repair, we must weigh what may be gained by the many available procedures The paramount thought should be to regain function and for this we need position of function This may be brought about by splinting, capsulectomy, arthroplasty, and arthrodesis

In planning tendon repairs and transfers, we must keep in mind the value of arthrodeses as by these we may obtain position of function when there are not enough tendons to give it. The fewer the tendons that are available, the more we need arthrodeses By these, many a deformed hand may be placed in good position so that the few tendons can furnish the opening and closing

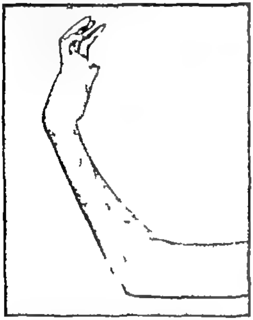


FIG. 251 Typical position of non function due to flexion of the wrist. Hidebound from burn of forearm. Needs liberation for nutrition by slitting and placing multiple linear skin grafts. If wrist had been in dorsiflexion, the hand would have been in the position of function. Contracture of all muscles exaggerates the deformity

for grasp For loss of deltoid, the arm is made useful by arthrodesing the shoulder A flail elbow arthrodesed brings function to the hand. Arthrodesis of the wrist stabilizes the hand for use and makes the five wrist tendons available for the digits The three large joints are rarely arthrodesed at once. Any one or two of the thumb joints may need arthrodesing, and any one or two of the three finger joints leaving some joints for motion. In loss of nerves muscles, or tendons enough joints in the limbs may be arthrodesed to give position of function and allow the remaining available tendons to furnish prehension and what other motions they can

SURGERY OF SPECIAL JOINTS

Wrist Joint

A wrist joint damaged by infection or injury presents a number of important principles to consider when contemplating repair Following infection it will be found that the wrist is ankylosed in flexion, a position of nonfunction This is because the flexor tendons and other tissues on the volar aspect of the wrist shorten, producing flexion contracture. The radio-ulnar joint always shares in the infection, so the motion of pronation and supination will be lost. For such an ankylosed wrist we should change the position to one of dorsiflexion, and either solidify the wrist by arthrodesis or give it motion through arthroplasty In either case, the motions of pronation and supination should be restored by disconnecting the lower end of the ulna from its attachment in the wrist. The repair of such a wrist is usually only part of an extensive repair involving all the tissues.

Following injury the wrist may be deformed from any of the various types of dislocation or from loss of some of the lateral carpal bones, making an irregular surface to articulate with the radius and ulna or the wrist may be involved in part or whole in arthritis resulting from degenerative disease of the lunate (Kienböck's disease), or of the navicular (Preiser's disease) or from old nonunion of a fractured navicular

For old dislocation through the carpus, the wrist should be opened through a lateral incision or a transverse or L-shaped dorsal incision, all restraining ligaments should be freed, traction on the fingers applied, and with a skid like instrument (Fig. 563) the dislocation reduced. It will usually remain so. The bones may readily be pinned in place if necessary by two Kirsch-

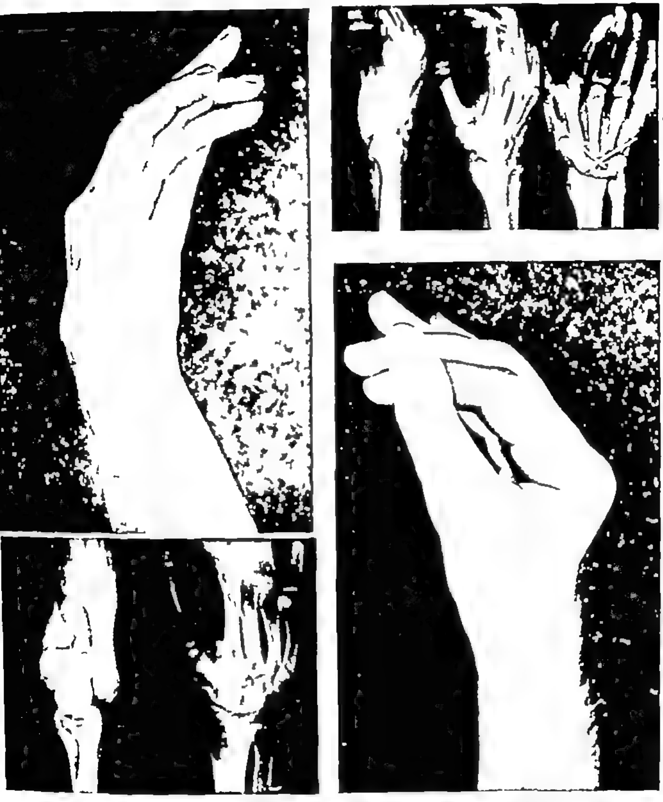


FIG. 252 Old carpometacarpal dislocation. (A and B *Left*) Deformity; Muscles are off balance. (C and D *Right*) Reduced surgically Balance restored (Courtesy of L. D Howard Lt Col. M C., Wakeman General Hospital.)

ner wires cut subcutaneously and removed in a month If the articular surface of the carpus is irregular and one-sided from loss of some of the carpal bones the remainder of the proximal row of carpal bones should also be removed or chiseled through, so that a properly shaped articular surface will present against the radius and ulna. For the arthritis resulting from degeneration of a carpal bone the offending carpal should be excised The symptoms will improve, but some of the arthritis will

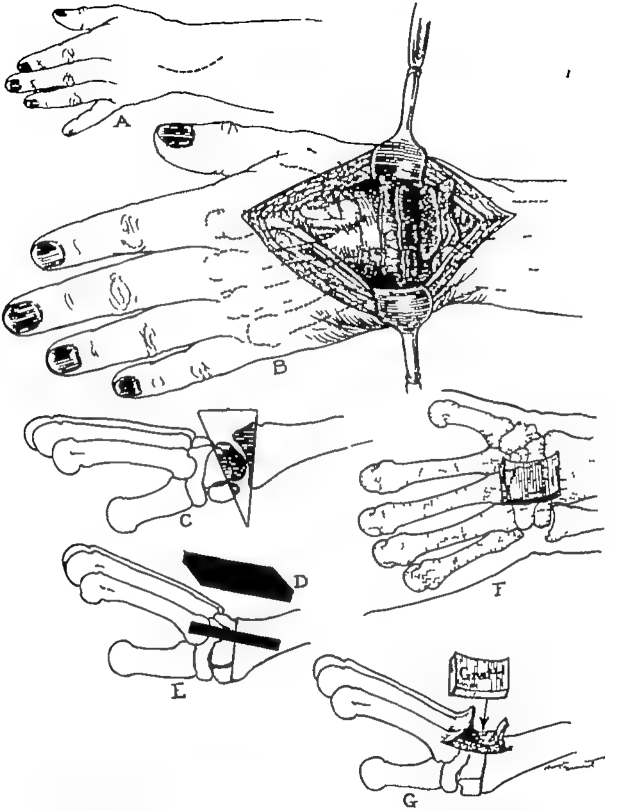


FIG. 253 Arthrodesis of the wrist joint with preservation of the radio-ulnar joint.
(A) Incision placed to spare branches of radial nerve and not to overlie the bone graft.
(B) Through an H-shaped cut in the joint capsule the latter is peeled back each way with a layer of bone.
(C, D and E) If growth has been attained and stability is desired a wedge resection is done and a bone graft is placed in the central portion of the bones through the epiphyseal line.
(F and G) Method used when epiphyseal plate is still active. Spongy graft from ilium is placed rather superficially and the capsule of the joint closed over it. Should dorsiflexion increase with growth, it can be later corrected by osteotomy

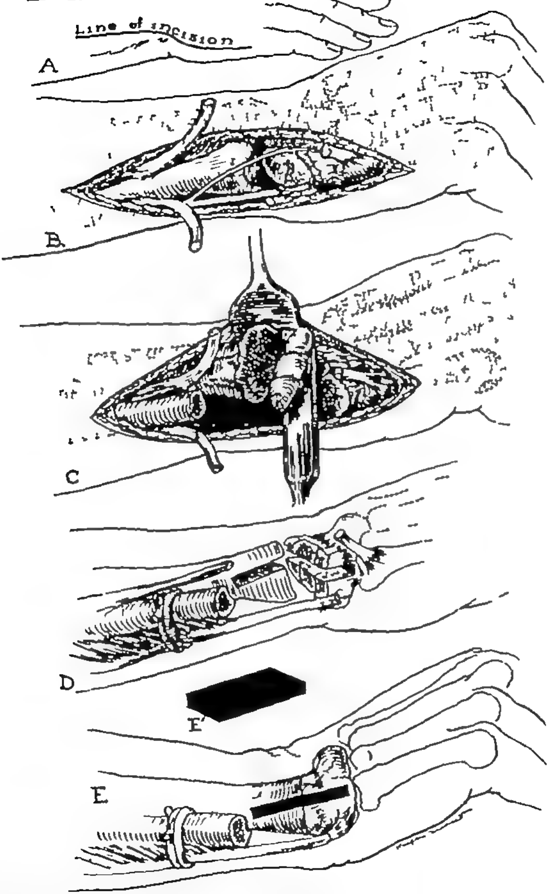
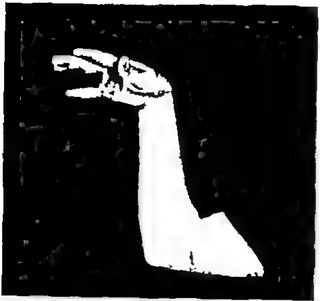
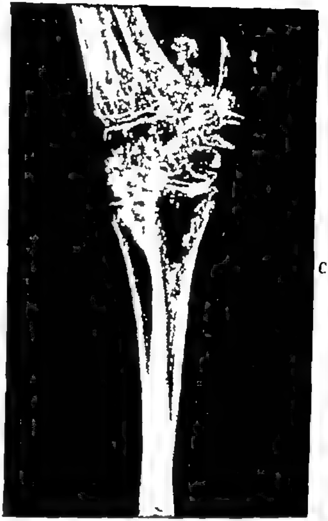


Fig. 254 Arthrodesis when the radio-ulnar joint participates in the ankylosis.
(A) The joint is opened by the Smith Petersen approach.
(B) Tendons of the two carpi ulnari severed and dorsal branch of ulnar nerve retracted.
(C) Head of ulna is excised and joint denuded so it fits together at 30 of dorsiflexion.
(D) The ulna now free for pronation and supination is lashed to the flexor ulnaris tendon to prevent displacement.
(E) Bone graft from tibia or iliac crest is placed.

A



B



C

FIG. 255 Case D T., aged 8 Volkmann's ischemic contracture from supracondylar fracture treated with elbow flexed in cast.

(A, *Left, top*) Condition preoperative. Flexors of wrist and digits are shortened and devoid of action.

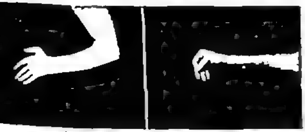
(B *Left bottom* and C, *above*) Wrist was arthrodesed sparing the radio-ulnar joint and the epiphyseal plate.

be permanent. If the wrist is sufficiently and progressively arthritic arthrodesis is indicated

In planning our wrist joint operation we should keep in mind that normally the wrist moves anteroposteriorly, laterally, and in circumduction, and that it also participates equally with the elbow joint in pronation and supination. Upon the position of the wrist depends the muscle balance of the fingers. The farther away is the position, from between 20 and 30° of dorsiflexion, the more are the digits off balance.

In a midcarpal dorsal dislocation the thumb, with its carpal row, may be left in a forward position in the palm just as if the abductor were paralyzed *It will have* poor function, cannot make an O with the index finger and cannot extend backwards. *Replacement of the bones is necessary*

FIG. 255 (D *Top*) At the same time tendon transfers were done
Extensor carpi radialis longus to flexor sublimus,
Extensor carpi ulnaris to flexor profundus,
Extensor carpi radialis brevis to flexor of thumb.
Removable running stainless steel wires securing tendon transfers for three weeks are shown.
(E and F *Bottom*) Show enough function that the hand is useful. With this hand the patient picks up eats, writes and grasps firmly from one to three of the examiner's fingers



E F

A dislocation about or through the carpus backwards or forwards so upsets the muscle balance or relative tension of the tendons

A

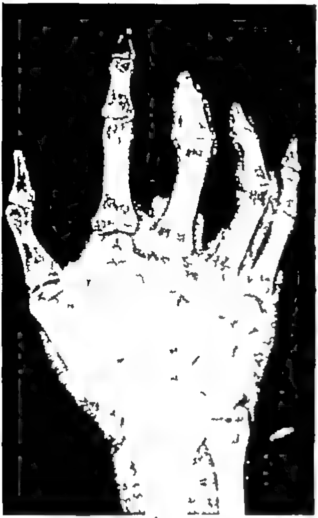
B

FIG 256 (A and B) Result of arthrodesis of wrist at 13 preserving the radio-ulnar joint and the epiphyseal plate. At 6 a supracondylar fracture was put up in flexion with a Velpeau bandage for three days. Large pressure sores developed in the antecubital space. The median nerve and great vessels were pinched off and severe Volkmann's ischemic contracture resulted. After arthrodesing the wrist and suturing the median nerve, useful function was attained by tenotomizing the flexors and the pronators and transferring four extensor tendons.

that there is resulting deformity of angulation in each successive joint distally This can be corrected only by placing the bones back in their normal alignment.

Often in paralytics the motion of the digits is automatic, depending upon the movement of the wrist, and will be lost if we produce an arthrodesis In choosing between arthrodesis and arthroplasty the following considerations may be of assistance

Following arthrodesis in 20° of dorsiflexion and providing that pronation and supination are free there is excellent function with very little disability Such a wrist is especially adapted to heavy work. For some people who do fine work, such as



A

B

FIG 251 (A, *Left top*) Loss of carpus from shotgun wound.
(B *Right top*) New skin supplied by tube pedicle.
(C, *Bottom*) Arthrodesis between radius and metacarpals using a large flat iliac graft. (Courtesy of Samuel Banks, Lt. Col., M.C., Wakeman General Hospital.)

C

musicians or women and also those desiring good cosmetic appearance, a movable wrist by arthroplasty is desirable This is especially so when there are ample tendons in good condition to move both the wrist and the digits If a wrist is ankylosed in in correct position, correction by either arthrodesis or arthroplasty is desirable. For spastic cases arthrodesis is better than arthroplasty This applies also to flail wrist and to any hands and wrists where there are not enough tendons to move both wrist and digits. Arthrodesis makes available for use on the digits the five or six tendons that normally move the wrist. When, however, the number of available tendons is few, we should weigh well between choosing arthrodesis or using the few available tendons to move the wrist *With a movable wrist*, automatic digit motion may be obtained by tenodesing their extensor and flexor tendons to the forearm bones. For extreme cases of clubhand, severe malunion about the wrist, or severe arthritis arthrodesis is desirable

For Volkmann's ischemic paralysis one can use either arthrodesis with shortening or resection of one or two rows of carpal bones. These procedures shorten the forearm so as to relax the shortened muscles and tendons Arthrodesis is usually chosen because the number of available muscles will be insufficient to move both the wrist and the digits If, however, the available tendons are too few tenodesis and automatic movements from wrist motion can be given as on page 291

Arthrodesis. Arthrodesis should not be done before the age of eight—or better, 10—years, because of distortion and interference with growth The optimum position to be obtained is from 15 to 30° of dorsiflexion, preferably 20° This will place the cleft between the opposed thumb and the hand in line with the forearm for grasping Also the wrist should be in slight ulnar flexion, so that the cleft between the extended thumb and the hand will be in the line of the forearm and the tendons crossing the wrist will be in their normal line of function

Two types of operation are available, depending on whether or not the lower radio-ulnar joint is functioning well If it is, the dorsal route should be chosen so as to keep away from this joint and preserve its function These cases are usually paralytic, rather than from traumata or infection If the radio-ulnar joint is involved, the lateral route, as described by Smith Petersen, is preferable.

For the dorsal route the incision should be curved, with the broad pedicle on the radial side to preserve the branches of the radial nerve. This is preferable to the bayonet incision across the wrist, as it places the suture line remote from, instead of over, the bone graft. As the soft parts of the wrist shorten, they broaden needing more skin circumferentially Therefore, this wound may be closed as a T juncture, the V Y principle being used. It has been suggested that the incision be a Y, the fork embracing the wrist and with the stem distal This is closed as a V, thus taking from the length and giving to the circumference. Entering between the extensor pollicis longus and extensor tendons of the fingers which are retracted to each side the capsule of the wrist is exposed A wedge is chiseled out across and including the radiocarpal joint so the bones will fit free from cartilage at 20° dorsiflexion With a broad chisel a transverse cleavage is made into both the radius and carpus either through the depth of the bones when placed in dorsiflexion or by shaving up their dorsal surfaces with periosteum and ligaments attached as flexible flaps The former adds somewhat to stability Usually this cut does not quite reach the carpometacarpal joints but when extra stability is desired as in congenital defect of the ulna it is extended into the metacarpals When carpometacarpal joints share in the fusion, some resiliency is lost and there is risk of breaking Cartilage from the *midcarpal*

joints is removed where accessible. Where stability is needed, a thin, flat graft from tibia is used, but a semiflexible graft from the iliac crest fits the dorsiflexion better and excels in bone growth properties Too large chiseled from radius and carpus. A broad slot to receive the graft is chiseled across the radius and carpus by the methods described under the dorsal approach. For a graft, the removed head and neck of the

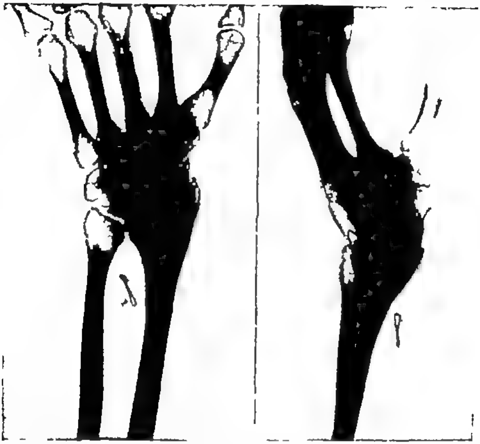


FIG. 258 Arthrodesis by bone graft at age of 20 in a case of lower brachial plexus palsy Radio-ulnar joint is preserved. Tendons at the same time transferred to move the digits.

a graft will stretch the limited circumference of the wrist. Before full growth is attained the work should all be done distal to the epiphyseal plate, the greater part of the wedge being taken from the carpus (Figs 253 and 254)

In the lateral approach through a lateral incision, jogged slightly dorsally as it crosses the wrist, the posterior branch of the ulnar nerve is preserved by retracting it volarward The head of the ulna is freed subligamentously, and with a short segment of the shaft is removed, exposing the wrist joint. The extensor tendons en masse are stripped and retracted dorsally The wedge for bony contact and dorsiflexion is ulna or the tibia or iliac crest are available.

If some of the dorsum of the radius proximal to the epiphyseal plate is involved in the fusion, and from growth, hyperdorsiflexion of the wrist results, this can later be corrected by osteotomy

If the arthrodesis is done for a wrist that has been solidified by infection it is not necessary to place a bone graft, but one is essential if the intercarpal joints are free. The cartilage should be chiseled from the midcarpal joint. If for tuberculosis, the onlay type of graft should be used. The short segment of the neck of the ulna is excised with the head to liberate the wrist for pronation and supination, not forgetting

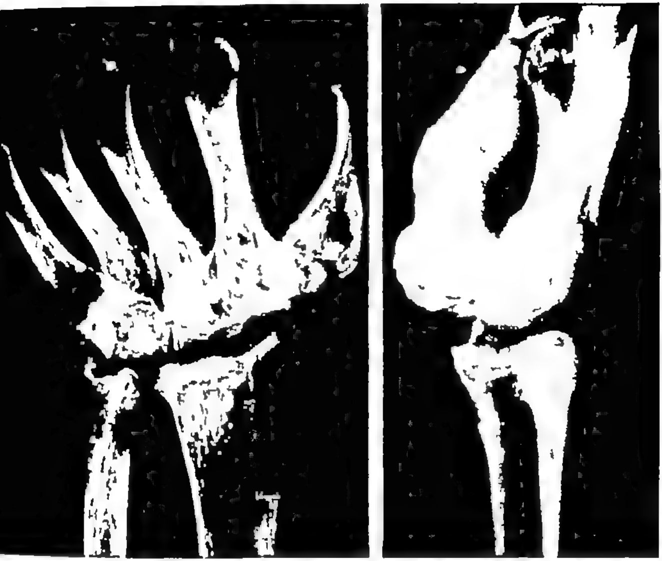


FIG. 259 Case A. F From a wrist joint infection starting in the ring finger the wrist had only 14 of painful motion.
(A and B) The proximal row of carpals and head of the capitate were removed. X ray films were taken a year later The wrist was strong painless had 30 of voluntary dorsal flexion and 30 of flexion amounting to 60 of motion.

to place the tendon sling described under this operation The arm and hand are then put up in plaster of Paris for two months, followed by immobilization by a splint for four months longer The first cast should be bivalved for the period of swelling There is so much postoperative swelling and the skin about the wrist yields so little that there is liable to be some necrosis of the skin. Should the skin be tight, freeing incisions with skin grafting should be done It is not wise to combine with the arthrodesis other operations, such as extensive tendon transfers, for fear of increasing the swelling and jeopardizing the tendons.

Arthroplasty In the wrist true arthroplasty is seldom indicated Here the operation usually consists of removing either the proximal or both rows of carpal bones Enough articular cartilage is generally found to furnish motion. If, however, after excising the necessary half inch of bone to furnish motion both of the surfaces are raw, so that granulations will grow across and rejoin the bones, a double or single layer of free graft of fascia lata should be interposed.

The usual procedure is to remove the proximal row of carpal bones This should be accompanied by chiseling off the pro-

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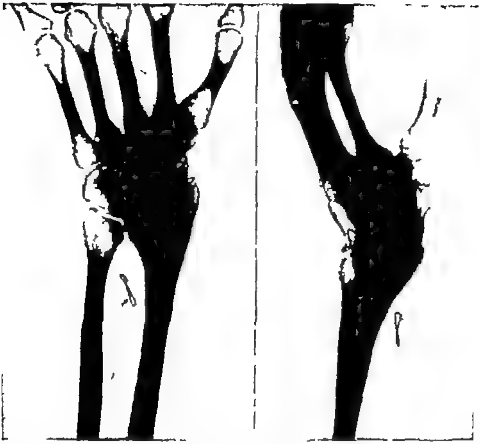

Fig. 258. Arthrodesis by bone graft at age of 20 in a case of lower brachial plexus palsy Radio-ulnar joint is preserved. Tendons at the same time transferred to move the digits.

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A B

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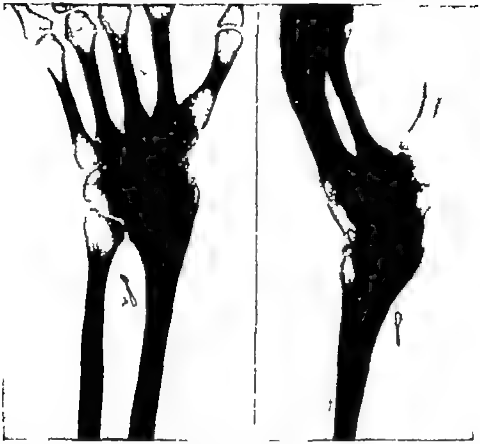

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The usual procedure is to remove the proximal row of carpal bones. This should be accompanied by chiseling off the pro-

of the ulna interligamentously but not subperiosteally, leaving the styloid process with its two ligaments The shaft is trimmed obliquely to avoid a corner A new short ulnar head may form, held in place by its ligamentous attachments

DISLOCATION TRANSVERSELY When the lower end of the radius is fractured backward or forward the ulnar head remains fixed, though relatively dislocating on the radius forward or backward, respectively Thus, in Colles' fracture it is fixed forward and distalward. The mechanism is similar to that of dislocation of the radial head in fracture of the upper end of the ulna. Also, forced supination dislocates the ulnar head forward without fracture unless the fracture is of the styloid process. Once dislocated there is free to-and fro movement between ulnar head and radius, and the former is prominent dorsally on pronation, displacing with a click on each motion of pronation or supination. The click is caused by the tendon of the extensor carpi ulnaris jumping back and forth over the ulnar styloid. In supination, when the wrist is flexed, the tendon displaces volarward, and when the wrist is dorsiflexed the displacement is dorsalward—each time with a snap Pain, tenderness, and weakness are noticed, especially when lifting in pronation.

Treatment Several corrective procedures are available, some of which are as follows

1 A tendon or fascial graft encircles close to the head of the ulna crosses, and is attached to the radius at the dorsal and ulnar borders of the radio-ulnar joint.

Another strip substituting for the stylotriquetrum ligament but advantageously oblique is half of the tendon of the flexor carpi ulnaris split down and left attached to the pisiform. It then penetrates the head of the ulna at the base of the styloid and is made fast.

A third tendon graft checks the tendon of the extensor carpi ulnaris from jumping over the ulnar styloid by looping around this tendon and fastening to the dorsal ligament of the wrist. Method used successfully by author (Fig 261)

2 Half of the tendon of the extensor carpi ulnaris is split off down to its insertion, brought back through the head of the ulna through a drillhole, and fastened to the bone (Taylor)

3 In case with accompanying arthritis, the head of the ulna is fused to the radius and a segment of the neck of the shaft is excised.

Postoperatively in any of the above procedures, to check rotary movements, the cast should include the upper arm and the elbow should be at a right angle.

Upper Radio-ulnar Joint. (See Chapter 11)

Synostosis Between Radius and Ulna. (See Chapter 11)

Finger Joints

Following injury or infection, or whatever keeps a hand swollen and stationary, finger joints stiffen, the proximal in extension and the middle and distal in moderate flexion Sometimes the middle joints assume a position of extreme flexion The positions the joints assume depend somewhat on muscle balance. Thus, in infections when the intrinsic muscles of the hand are bathed in pus, as is also their ulnar nerve, so that these muscles are not functioning, the proximal finger joints remain in extension and as their collateral ligaments shorten and thicken become fixed so In the middle finger joints the collateral ligaments are tightened the most at right angled flexion. In greater or less flexion these ligaments are relaxed. Therefore, when the middle joints become fixed in either of these positions it will be necessary to sever the collateral ligaments before the joints can be either extended from extreme flexion or flexed from a position of extension

Capsulotomy, which consists of excision of the collateral ligaments, is very effica

cious in the proximal finger joints, but only moderately so in the middle and distal finger joints.

Arthroplasty yields fine results in proximal finger joints because as they are not weight bearing, they are less time limited and these joints are stabilized by tendons on four sides In middle or distal finger joints instability—either to and fro or lateral in direction—is apt to result When grasping firmly this is less noticeable. These joints have practically only two tendons and no lateral control Arthroplasty of the middle finger joint has been successful, giving mo-

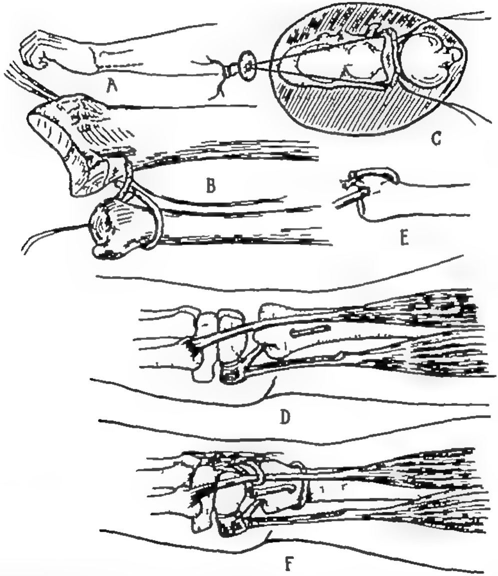


Fig. 261 Operation for chronic dislocation at lower radio-ulnar joint.
(A) Incision. Dorsal branch of ulnar nerve is spared.
(B) Tendon graft, such as palmaris longus, is placed around neck of ulna, crossed and imbedded into the radius in slits just above and below the socket for articulating with the ulna. This substituted for the radio-ulnar ligament.
(C) End view showing method of attaching tendon ends in slits. Stainless steel wire No 34 is attached to a tendon end, both strands passed through a drillhole in the radius and out the other side of the limb. They are tied there over a button. The wire is withdrawn backward in three weeks by the pull-out wire.
(D and E) A half thickness strip of tendon of flexor carpi ulnaris is split off retaining its attachment to the pisiform bone It substitutes for the stylotriquetrum ligament by passing through an oblique drillhole in the head of the ulna There it is turned back and sutured to a ligament. The pull of this ligament is distal and volar checking dorsal dislocation
(F) To prevent the tendon of the extensor ulnaris from snapping over the styloid process in flexion of the wrist, a small tendon or fascial graft loops about it and is fastened to the dorsal ligament of the wrist joint.

tion to as much as 70° A requisite, however, which is rarely present, is that all of the other tissues about the joint be normal. Luck claims to have obtained 90 degrees by temporarily inserting a curved disc of stainless steel. If too large, the disc sloughed out. If curved in two directions, the disc could not be withdrawn. When a proximal finger joint is ankylosed it is better to perform an arthroplasty, but when a middle or distal finger joint is stiff it is preferable either to amputate the finger through the middle joint or to shorten it by arthrodesing the middle or distal joint at an angle of semiflexion. A stiff finger is better amputated, but if shorter and in semiflexion it may not be too much in the way

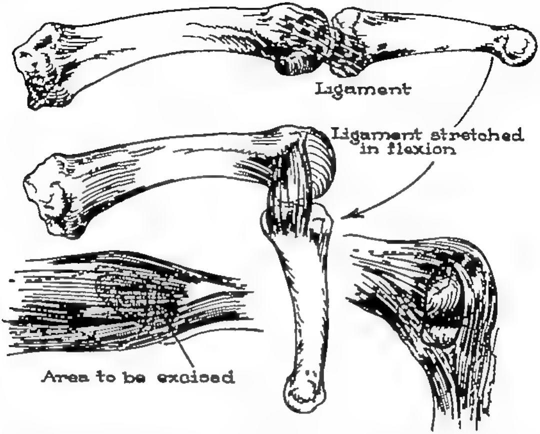


FIG. 262 Capsulectomy of the proximal finger joint. Normally the collateral ligaments are slack in extension but tight in flexion. If these ligaments, because of edema and immobility become short and thick, the joint will no longer flex.

Through a short longitudinal incision on each side of the knuckle the joint capsule is exposed between tendons of long extensor and interosseus muscles and on excising the collateral ligament from each side the joint can easily be placed in flexion. Method shown in Fig 263 is preferable.

Proximal Finger Joints. CAPSULECTOMY This is frequently needed and is indicated much oftener than is arthroplasty When proximal finger joints are ankylosed in extension, as they usually are, the choice between capsulectomy and arthroplasty is dependent on the roentgen appearance of the joint. When the joint is intrinsically in good condition, the extensor tendon is not adherent on the dorsum of the hand and the intrinsic muscles are working Capsulectomy usually gives excellent function, the joint eventually gaining a range of motion from 70 to 90° depending of course, on the quality of the surrounding tissues.

Through a short, straight, dorsilateral incision on each side of the knuckle, the aponeurotic hood is exposed. The tendons of the interosseus muscle may be seen and retracted By movement the joint is located and the site of the collateral ligament deter

mined The aponeurotic hood covers the collateral ligaments In a burn or infection case where there is much cicatrix, it may be necessary to excise not only the collateral ligament but also that portion of the thickened aponeurotic hood that covers it. With a pointed knife a wide oblique ellipse including the collateral ligament and that part of the aponeurotic hood is excised This should be done thoroughly so that no tabs of ligament remain. If done too widely, the joints may dislocate

In the average case the aponeurotic hood may be spared excising the collateral ligaments only This has been done by retracting the hood distally or incising it vertically, but the best method (devised by Howard) and the one we use routinely is as follows When the long extensor tendon is split longitudinally and retracted, the capsule of the joint and the collateral ligament on each side under the aponeurotic hood can be seen. With pointed scissors these ligaments are excised Often, too, in order to allow flexion, the capsular ligament must be cut across Later the split in the extensor tendon is closed by a removable running stainless steel wire brought out through the skin at each end. On excising the collateral ligaments and severing across the internal capsule, it will then be found that with very little force the end of the proximal phalanx can be shoved around the head of the metacarpal into the capsular pouch until the joint is in full flexion This, by the way, is the motion the patient should use afterward in exercising the joint. In long-standing cases before the phalanx can be shoved around the flexion pouch must be prepared to receive it. With a probe or curved elevator the pouch is restored by stripping the anterior capsule from behind the volar part of the metacarpal head Unless the phalanx is made to slide around the metacarpal head the joint merely opens like a book. In fact, one often sees a transverse groove eroded across the head of the metacarpal where the base of the phalanx has impinged It is not sufficient merely to strip the collateral ligaments from the metacarpal heads and let them displace distally, nor is it sufficient simply to cut them through as in classic capsulectomy, for these ligaments, which are usually greatly hypertrophied and thickened, will after these two conservative procedures merely reunite and again stiffen the joint. They must be excised. The joint is put up at nearly a right angle by a dorsal splint of plaster of Paris for ten days until the tissues heal in this position, after which elastic splinting is continued as long as is necessary as described together with some requirements for success after arthroplasty

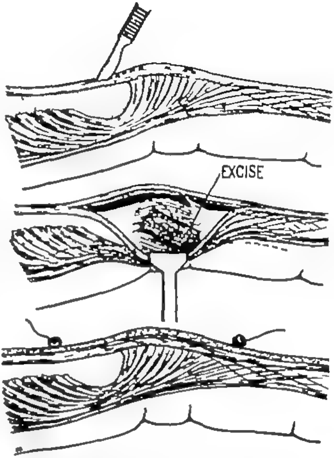


FIG. 263 Capsulectomy Collateral ligaments are best exposed by splitting longitudinally the long extensor tendon (L. D Howard) This exposes the superior capsule the two collateral ligaments and the tendonous slip to the proximal phalanx when present. *After excising completely both collateral ligaments the slit in the long extensor tendon is closed by a removable running stainless steel wire.*

A

B

FIG. 264 (A, *Top*) Dorsal burn from air plane fire leaving stiff recurved proximal finger joints.
(B *Bottom*) Capsulectomy through split skin graft allowed flexion. Central tendon slips of middle joints have been burned, necessitating arthrodeses. (Courtesy of L. D Howard, Lt. Col., M.C., Wakeman General Hospital.)

If, in resistant cases, some of the aponeurotic hood is excised, together with the collateral ligament, and one does not guard against luxation, the extensor tendon may luxate ulnarwards or the joint may dislocate volarwards, both requiring correction by replacing some ligament or by pinnings

The skin over the knuckles is often too tight to allow flexion of the joints as in cases of long standing, dorsal cicatrix, or skin contracted from a burn In such a case the skin is cut transversely across just back of the knuckles, allowed to gap on flexion, and then covered by a free skin graft. As the capsulectomy was done under the aponeurotic hood, the latter will serve as a vascular bed for the skin graft.

Capsulectomy is frequently done at the same time that a malunited metacarpal is repaired. Also at the same operation the long extensor tendons may be freed and gliding material inserted beneath them Some essentials for capsulectomy are mentioned below at arthroplasty of these joints.

ARTHROPLASTY Through a dorsolateral incision 1½ inches long the proximal finger joint is exposed, entering it between the tendon of the interosseus muscle and the dorsal aponeurosis which caps the joint. The phalanx and metacarpal are then stripped of their surrounding capsular ligament and separated or even chiseled across if necessary Usually there are some remains of articular cartilage on the phalanx. Enough of the head of the metacarpal is excised to make a space between the two bones of about 1 cm and the tissues about the metacarpal end are well freed for three-fourths of an inch including the volar capsular pouch The head of the metacarpal is then carved by chisel and anvil to receive the phalanx, so that its end is almost flat in the lateral plane but is rather sharply rounded and facing slightly volarward in the anteroposterior plane. Over this is fitted a small hood of thin, deep fascia taken from the lower part of the thigh, forward from the region of the fascia lata or else a sheet of paratenon from over the fascia lata This is made to fit over the metacarpal head and clasp about its neck with a purse-string suture of very fine chromic catgut. Sometimes two additional side sutures are necessary to hold the hood proximally

If the extensor tendon is adherent for a distance on the back of the metacarpal it is well to prolong the dorsal portion of the hood far enough backward to prevent re-adherence. The hood should separate from the metacarpal all of the tendons on the four sides so they will glide. The hand is put up in a dorsal plaster of Paris splint, keeping for two weeks this joint well flexed to near a right angle. Following that, elastic traction is used. At the end of the first week, while still in the plaster of Paris, and when the danger of blood clot formation between the bones is over, longitudinal skin traction by Ace adherent may be used by

a rubber band pulling from a wire outrigger The plaster of Paris keeps the joint flexed and the traction separates the bone ends Following these first two weeks, the plaster of Paris is discarded and flexion is main

a rocker effect of the phalanx on the narrow edge of the metacarpal Passive flexion may be greater than voluntary because the intrinsic muscles may, until they have taken up the slack, be too loose

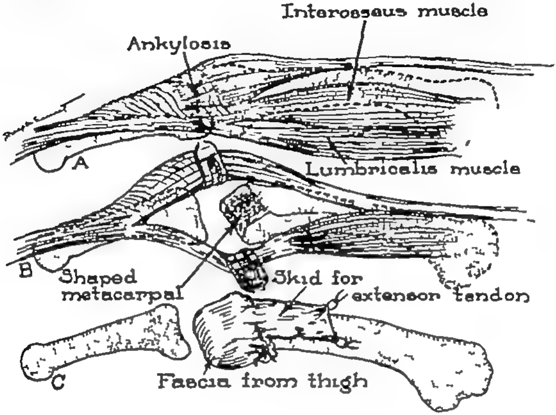


FIG. 265 Arthroplasty for ankylosis of proximal finger joint. Gives about 70° of motion. The prolongation proximally of the fascial hood is used in case the extensor tendon is found adherent to the bone.

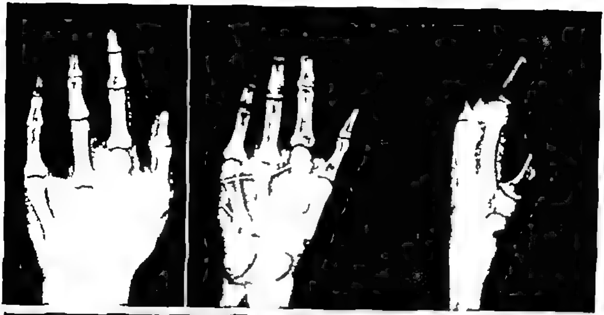
tained by leather cuffs looped over the prox imal phalanges and pulled by rubber bands to an outrigger The outrigger of wire is fastened either to a volar plaster of Paris slab or a metal cock up splint. Another method of maintaining the flexion is by the knuckle bender splint. After either capsu lectomy or arthroplasty it may be necessary to persist in the use of elastics to maintain flexion as long as there is any tendency to lose it. This may require even two months.

The usual degree of flexion gained in civil cases is 70 degrees though it may be somewhat less if the tissues are quite cicatricial After gunshot wounds 90 or 100 degrees may be obtained because the scar tissue was in only a limited area unlike that from in fection. We cannot expect to produce a sliding joint like the original but can give

Essentials for success in either capsulec tomy or arthroplasty are the presence of good surrounding tissue, good nerve supply and nutrition, redundant dorsal skin good working muscles about the joint, free ex tensor and the intrinsic muscles or some correction for them to furnish strong flexion Preoperatively, the presence of active in trinsic muscles is determined by feeling for the lateral bands and observing lateral motion and voluntary extension of the distal two finger joints.

A requisite to success in arthroplasty is integrity of the intrinsic hand muscles to maintain the flexion gained If due to the original trauma or paralysis of the ulnar nerve function of these muscles is missing voluntary flexion of the proximal finger joints may be restored as follows The

A



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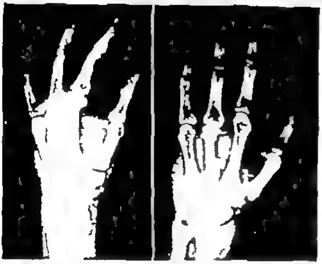


Fig. 266 Case R. E. J Metatarsal grafted into metacarpal.
(A) From a gunshot wound, most of the third and fourth metacarpals were lost.
(B) The distal two-thirds of the fifth metatarsal, together with the head and the joint capsule, were pinned in place on the stub of the third metacarpal. The fifth metacarpal was dislocated over and pinned to take the place of the fourth, narrowing and loosening the hand.
(C) Good union. Joint structures preserved. 70 degrees of flexion.

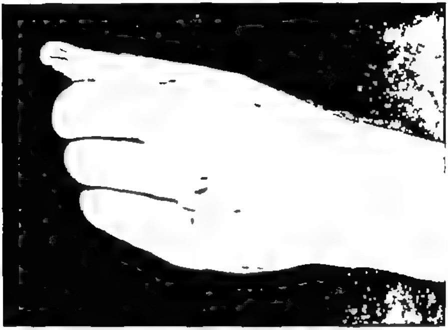
proximal pulleys of the fingers opposite the metacarpal heads may be slit on each side and advanced forwards so the long flexor tendon will displace forward sufficiently to give enough of an angle of approach to flex the proximal joints Another method is to transfer the flexor sublimis tendon down the lumbrical canal to the lateral band of the aponeurosis Some strong flexor is needed to maintain the flexion (Chap 10) Another requirement in arthroplasty is proper muscle balance *This may be upset* from angulation of the forearm bones, wrist or metacarpals tightening the extensors, causing hyperextension of the proximal finger joints and tightening the flexors causing clawing In such cases, proper bony alignment must first be reëstablished

In extreme cases of hypertrophic arthritis, arthroplasty of the proximal finger joints with resection of the metacarpal heads has been quite successful.

Grafting Half a Joint. When the metacarpal head is missing the shaft and the head of a fifth metatarsal may be grafted in place, bringing with it the joint capsule to fasten around the base of the phalanx. *A case of the author and several of Graham* showed 70 degrees of smooth motion after 8 and 10 months

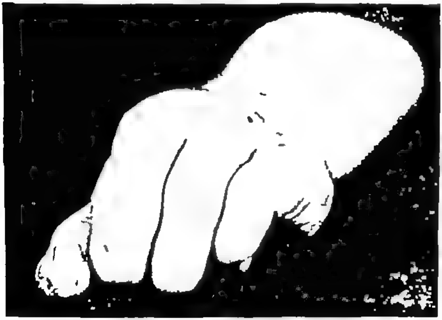
Grafting a Metacarpophalangeal Joint. Free grafting has been done several times using the joint of a toe or other finger Some became infected or arthrodesed, but others (Cuthbert) retained fairly good motion Some digits grafted by the pedicle method retained good joint motion, especially when the nerves were joined

Middle Finger Joints As above mentioned, capsulectomy is only moderately successful here and arthroplasty may give lateral instability Arthrodesis at an angle of moderate flexion, together with shortening of the finger, is a useful procedure. Union of the bones can be assured if they are either pinned together by two fine Kirschner wires made to cross each other to prevent distraction, or are joined, using a small flat key bone graft Limitation of motion in the middle and distal finger joints is difficult to correct surgically because the tissues are so thin and are in such intimate contact



D

FIG. 266 (D and E) Final appearance. Hand was much improved. A year later there was 70 of smooth motion in the joint. (Operation by the author in Walter Reed General Hospital. Photographs of Army Medical School.)



E

For hyperextension of proximal finger joints Howard chiseled off a flake of the dorsum of the metacarpal head and slid it distally partly over the phalanx. This checked the hyperextension of the proximal

FIG. 267 Arthrodesis of middle and distal finger joints in moderate flexion in burn case with tightly clawed fingers. Central tendon slips and middle finger joints have been burned. Pins are crossed to prevent distraction. (Courtesy of L. D Howard, Lt. Col., M.C., Wakeman General Hospital.)

joint, thus allowing the extensor apparatus to extend the distal two finger joints

Arthroplasty on the middle finger joint should be done only when all other tissues in the vicinity are normal. The incision should be lateral and away from the lateral bands of the dossière. There should be a space of at least ⅛ inch between the ends of the bones, and, postoperatively, flexion and traction should be maintained As mentioned above, the operation is only moderately successful Usually only moderate motion is obtained, and the joint is unstable laterally except when under the strain of gripping Tantalum hoods and stainless steel or vitallium caps have been used. They irritate and should be removed. Good motion has sometimes been obtained though lateral instability is a disadvantage.

Abnormal lateral mobility from tear of a lateral ligament can be corrected by a free fascial graft, contacting it well to the bone on each side of the joint. This is quite successful, though in some cases—perhaps where some low-grade inflammatory process is present—such a new ligament may melt away in spite of the absence of drainage.

Flexion contracture of the middle finger joint is common, and when long-lasting it involves the volar capsular ligament, together with the two anterolateral bands which are the collateral ligaments. These must all be severed before the joint will straighten Due to traumatic overextension of the middle finger joint the anterior capsule ruptures, healing with hyperextension but often with flexion contracture. At operation, this anterior part of the capsule of the joint is found to be greatly thickened. It can even be excised, but postoperatively there will be an unavoidable tendency for the flexion contracture to recur Occasionally, when the anterior capsule has been entirely excised, it will be observed in cases where the flexor tendons of the finger are not functioning strongly that the middle phalanx luxates backwards, necessitating arthrodesis with shortening.

Arthrodesis of the middle joints, best with some shortening, is useful for sharp flexion contractures following burns of the dorsal joint capsule. Two crossed Kirschner wires will hold the bones while fusing, the crossing preventing distraction. When placed, the bones should be firmly pressed together so that the crossed wires will not make distraction and hence nonunion

Distal Finger Joints. These are like the middle joints, but are so in miniature

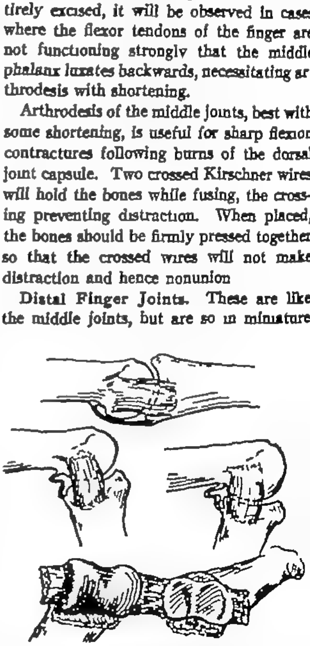


FIG. 268. Middle joint of a finger showing collateral ligaments and close fitting joint surfaces on which depends the lateral stability Snug-fitting joints are easily stiffened.

Fig. 269 (A) Old dislocation of first metacarpal forward on the greater multangular (B) A stable thumb was obtained by open operation. The débris was removed from between the two bones and the bases of the first two metacarpals were lashed together with palmaris longus tendon through drillholes.

that seldom is surgery applicable, except to fuse them in slight flexion This is useful in hyperextension from burns and, also after a flexor profundus tendon alone has been severed and the tendon has been for long contracted into the palm. The term base ball finger is too inaccurate as it has been used for evulsion of the insertion of the extensor tendon from either the middle or distal phalanx or deformed finger joint from sprain or fracture

Old Dislocation of Finger Joints. Usually finger joints are easily reduced and stay reduced, but often enough, in spite of repeated attempts, they do not, and the distal bone remains displaced dorsally on the proximal Whether it be middle or distal finger joint or proximal or distal joint of the thumb, operative reduction is necessary This can be done by enlarging the volar rent in the capsule. It will be found that the proximal bone has ruptured through the anterior capsule of the joint, so that this capsule lies between the two bones, preventing reduction As soon as this capsule is removed from between the two bones the dislocation will reduce easily and remain so The eventual result, how

ever, will be considerable limitation of movement of the joint and even ankylosis if the dislocation has existed too long In cases which are operated upon within three weeks, there should be good restitution of motion.

shorten this ligament by overlapping it, but also to add by fascial graft an additional reinforcing ligament over it, contacting it intimately to raw bone on each side of the joint.

Irreducible dislocation in the distal or

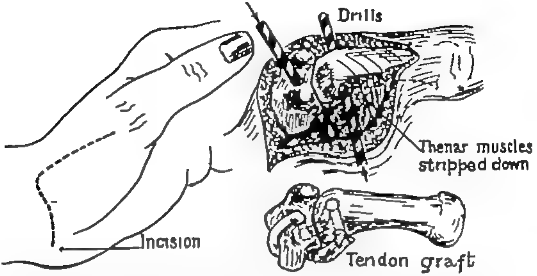


FIG. 270. Operation for correction of chronic dislocation of first metacarpal on greater multangular The former is drilled laterally and the latter anteroposteriorly and the tendon graft from palmaris longus is threaded through the holes as shown, looping it under the ridge, lashing the metacarpal down so it cannot displace backward. Fusion is better if arthritis is present.

Joints of Thumb

Distal and Metacarpophalangeal Joints. Either the distal or the metacarpophalangeal joint of the thumb may be arthrodesed in semiflexion. It will give a useful thumb with very little disability If the carpometacarpal joint of the thumb is hopelessly stiffened with the thumb in a backward position, due to infection or injury, it is best to resort to a rotary angulating osteotomy of the metacarpal of the thumb, so as to place the thumb in the functional position of opposition.

The dorsolateral ligament of the metacarpophalangeal joint of the thumb frequently suffers a transverse rupture from delivering a swinging blow in boxing when the thumb is not clasped over the fist. If the thumb is at once put up in plaster in full extension and abduction there will be no disability In a neglected case, however, it will be necessary not only surgically to

the metacarpophalangeal joint of the thumb is similar to that seen in the middle and distal joints of the fingers, though in the case of the metacarpophalangeal joint the head of the metacarpal protrudes through the base of the anterior capsule of the joint and becomes entangled between the two heads of the short flexor muscle of the thumb If closed reduction by manipulating the phalanx over the head of the metacarpal is unsuccessful, open reduction by a lateral incision, drawing the tendon of the flexor brevis muscle and the volar part of the capsule away from between the two bones, will allow easy reduction. The joint is put up in moderate flexion for two weeks.

Carpometacarpal Joint. In case of ankylosis of this joint with the thumb in the lateral position or of painful motion from arthritis in the trapeziometacarpal joint, considerable motion of the thumb and good function can be obtained by arthro-

FIG. 271 Dislocation of first metacarpal on (A) greater multangular successfully corrected (B) by a graft of palmaris longus tendon spanning across the center of the joint as in the Nicola operation. (Case of Dr Slocum personally seen.) (Courtesy Capt. D B Slocum)

desing the carpometacarpal joint in the functioning position of opposition providing that the navicular is free to move. The navicular bone will furnish enough motion unless there is roentgen evidence that the other joints of the thumb are also affected For chronic dislocation, painful from arthritis arthrodesis is best.

In arthrodesis, the joint is uncovered through an L-shaped incision, one arm of which is along the dorsum of the metacarpal and the other following the flexion crease around the thenar eminence (Fig. 270) After the joint cartilage is removed with an osteotome, the bones are approximated in the correct position and pinned so temporarily, by two Kirschner wires cut off beneath the skin A small key graft is advisable if the Kirschner wires are not used.

If the carpometacarpal joint is ankylosed motions of the navicular on the carpus may also be limited In this case arthroplasty of the carpometacarpal joint can be done. A piece of fascia is interposed and the base of the metacarpal is so beveled that it will present a projecting hook in front of the multangulum to prevent backward dislocation. Patterson reported a result of full range of motion and good use of the thumb

Chronic dislocation backward of the carpometacarpal joint of the thumb occurs as a direct result of injury rupturing the capsular ligament and as a secondary effect of the malunited Bennett's fracture Normally, the projecting process of the volar edge of the base of the metacarpal hooks around the multangular bone, preventing backward dislocation. In a Bennett's fracture the metacarpal displaces backward and proximalward so that malunion occurs, leaving the metacarpal without a hook to hold it forward on the multangulum The metacarpal then, each time the patient

A

B

FIG. 272 (A, *Left*) Trapeziometacarpal joint was painful from old partial disloca tion.
(B *Right*) Arthrodesis using small bone chip Motion was then nearly painless.

grasps with the thumb, dislocates backward on the multangulum. This is accompanied by pain, weakness, and disability Opera tive correction may be found in Chapter 13, under Fractures

Backward dislocation of this joint may be corrected by performing a wedge osteot omy on the base of the metacarpal of the thumb, the wide part of the wedge being dorsal, so that when the bone ends are then forced together the articular surface of the metacarpal will form the necessary forward projecting hook around the multangulum to prevent the dislocation At the same time some fascial grafts can be applied to the dorsum and radial side of the joint to reinforce the torn ligaments. In Fig 270 is shown a method, used with success by the author, of lashing the metacarpal to the trapezium with a strip of tendon or fascia through drillholes. Another method used by Slocum (see Fig 271) is to place a ten don through a central drillhole through the two bones as in the Nicola operation on the shoulder Others using this method give conflicting reports, some good, some with pain from arthritis and some with shearing of the tendon Eggers, after slitting down a strip of tendon of the extensor carpi radialis longus and anchoring it to the trapezius, reports a satisfactory result.

Following plastic repairs of this joint, some cases in which arthritis has been pres ent continue to be sore. A more reliable cure is by arthrodesis. By this almost full thumb motion may be gained with the single exception of the ability to place the thumb behind the hand.

Rheumatic Finger Joints Any of the joints of the hand may become distorted, angulated and subluxated. Early they may be drawn into position by mild spring splinting.

The proximal finger joints may be so flexed that they luxate. Commonly there is excessive ulnar flexion Correction of these is at first by mild spring splinting For ulnar flexion the extensor proprius ten don of the index and little fingers may be split and each of the four slips inserted into the radial side of the proximal phalanx of a finger Finally the metacarpal heads may be resected.

The middle finger joints frequently show such hyperextension that the fingers cannot grasp Because of fluid distention in re-

peated flareups the anterior joint capsule becomes relaxed, resulting in the deformity seen in double jointed people, namely, hyperextension of the middle joints and flexion of the distal Intrinsic muscles shorten. The joints may stiffen in these positions. They may be drawn by padded clock spring into semiflexion and fused so

A thumb may show excessive flexion in its proximal joint and extension in its distal, or the distal joint may be angulated laterally from gripping by the fingers These joints may be fused in positions of function The intrinsic muscles become fibrously contracted as part of the rheumatic process and secondarily from posture and disuse They cause and perpetuate the deformity of the intrinsic plus position (see p 231)

OCCUPATIONAL THERAPY FOR CRIPPLED HANDS

Occupational therapy achieves real success in reconditioning crippled hands It should commence as soon as consistent with the healing of the wounds and be continued until the time of reëmployment. It is important to treat the patient as a whole as well as the injured part to keep the patient both physically and mentally a worker instead of an invalid. The activity selected should be of interest to the patient, who should then be spurred on by competition and the joy of accomplishment with a creative object and interest. Before resorting to occupational therapy, position of function should be brought about by spring splinting, and maximal improvement in the hand in general should be obtained by surgery

Improvement on use is a natural response to voluntary activity Contrariwise to the "degeneration of disuse there is revivification of tissues on voluntary use and the will to do Herein lies the superiority of O T over P T Physiotherapy seems to be of value in the first two weeks as a starter The passive part of physiotherapy has very limited value The active part is beneficial such as turning against weight or friction resistance, axles or T handles, drawing up weights by finger action, loosening the wrist or shoulder by turning the handle of graded sized wheels, gripping blocks, rice or rubber sponge and massaging hands in soapsuds Physiotherapy is necessary for paralyzed hands as the patient cannot use them It should be used for a long time Joints should be worked into the position of function aided by elastic splinting, and, together with all tissues, kept supple by passive movements and massage. The patient should be made to do this intermittently throughout his waking hours with his other hand

A patient often actually inhibits all movement of his injured hand, because he has detached his hand from his brain, at first he cannot use his hand Such a candidate for occupational therapy will, in his response to his interest and desire to work, gradually use his hand and then find that he can use it. The interest of the work causes him to activate his hand. Any light occupation with his hand, even modeling or painting has value as it will serve to reconnect his hand to his brain He later will change to occupations of real exercise

If the patient on first efforts tenses all of his muscles, he should be instructed first to relax and then to perform the purposeful movement. Once done these motions should be repeated often enough to become a habit with well-executed pattern The various motions may be taught until finally the patient becomes engrossed in what he is doing rather than in performing the certain motions If he has been beaten down by frustration from repeated failures and his fear of attempting, his morale should be rebuilt by encouragement and praise to restore to him sufficient confidence so that he will keep trying until he succeeds At first his hands are atrophied lame, weak and clumsy, but with encouragement and use there will be an increase of range of motion tone muscle action and co-ordination The brain again will take over the control of the hand As the work increases

and even greater tasks are undertaken, there will develop strength endurance and skill. For this rebuilding of morale and creating interest and ambition in work, there is no greater stimulus than the influence of attractive young girls who have personality plus It also has been my observation that these girls are extremely happy in their work.

Skill is developed by constant and thoughtful repetition of purposeful movements but *strength develops in response to overcoming graded resistance* Endurance may not be in proportion to strength. It increases by training and is due to quality of both nerve impulse and muscle contracture. *For endurance it is necessary to* build adequate blood supply to the muscles to furnish oxygen and carry away carbon dioxide and lactic acid Exercise increases the number of capillaries and brings latent muscle fibers into use but it does not increase the number of muscle fibers It increases the proportion of connective tissue in the muscles and the amount of sarcolemma, giving the meat a coarse reticulated appearance. Muscle of great endurance is darker, as the increased vascularity results in a greater hemoglobin content.

A good principle is to have the patient use the injured part to turn an axle or T handle to run machinery, by which, in turn, he is making something by sanding, boring, sawing, etc. In his interest in doing the job he takes his mind off his injured hand. In driving machinery by hand, the graded brake helps by gradually increasing the resistance

Occupational therapy should be prescriptional instead of recreational so that every activity will count in limbering up the parts of the hand that need it. The doctor should send to the occupational therapy department a prescription of just what the hand needs, such as flexion of the proximal finger joints, opposition of the thumb and dorsiflexion of the wrist. The occupational therapy department should then start the patient doing the special activities listed as beneficial for each item in the prescription.

An hour a day of O T is not of much use. It should be continued all day Also, portable apparatus should be taken to the hand ward and placed on bedside tables so there may be continuous use. All of the work of *the ward may be done by the patients*, and a spirit should be instilled into them continually to use their injured hands When a soldier returned from a month of furlough, during which he worked with his hands, the improvement in their use was especially great. Two or three weeks of occupational therapy makes considerable improvement, and two or three months, great improvement. Sanding blocks are very useful They should be low and squatty so as not to tip over, and shaped to bring about flexion in the finger joints, especially the proximal ones, and opposition of the thumb Some have holes to receive these digits in the proper positions. A block may be modeled from the impression in clay while grasping it Some have mushroom rounded tops, some are curled over like the crest of a wave and some have a gable over which to bend the proximal finger joints. The other hand presses the hand on the block as the sanding is done. Files, chisels and hacksaws are arranged on a rack with graded sized handles The patient starts with the large size, and, as the work progresses he can use ever smaller sizes.

The following suggestions were gathered from different Army general hospitals as to which procedures are useful to bring about certain desired movements in hands The enclosed chart which is abridged and modified from that developed at Lawson General Hospital covers many of these, and in addition, there follows a list of special suggestions for the commoner accomplishments that are most needed in these hands. The evaluations of these procedures were furnished by Maj Ivan C. Smith, Chief O T Department, Billings General Hospital.

To Flex the Straight Stiff Proximal Finger Joints (Most Prevalent Need)

Sanding blocks are made to fit a hand so

when the hand grasps it and is pressed on with the other hand in sanding, the proximal finger joints are forced into flexion over a fulcrum The fulcrum may be a rounded, gable-like angle or be rolled over like the crest of a wave There are round holes into which the fingers are held flexed and a side hole to hold the thumb in opposition Excellent.

Weaving The shuttle is held so that its edge acts as a support under the proximal finger joints. Not good if deformity is great because grasping shuttle does not give resistant force.

Graded handles A set of files, other tools or a printing press is made with handles graded in sizes from 2½ to ½ inch in diameter These are round or rounded triangular in cross-section for better leverage. Excellent.

Cord knotting Strings to be wound over small blocks of wood which gives forced flexion of proximal finger joints holding the blocks of wood Good

Scissor cutting Using materials of graded thickness. Not interesting for patients and tiring if hand is weak.

Clay mixing and modeling Excellent.

Flexion of All Finger Joints

Flat rectangular blocks with rounded edges to carry in pocket to grip upon

Graded sizes of tool handles Excellent

Clay modeling Excellent.

Sanding blocks Excellent.

Graded blocks to place on end of back saw

Running useful machinery by gripping and turning an axle. Excellent.

Gripping with hands in warm soap and water

By compressing a rubber bulb air is pumped until a record degree of pressure is attained or so that water is forced from one bottle to another Excellent

All the minor crafts and other activities are shown in chart.

Extension of the Fingers

Sanding with blocks with rounded tops and graded in size force fingers into extension The other hand is placed on top to gain stronger and maximum extension Excellent

Paper cutting holding paper flat and firm for hand-operated paper cutter Good

Pattern making In tracing patterns the fingers are strained in extension, holding the template down flat. Good but lacking in interest.

Clay modeling Spreading soft clay into pan like molds for making tiles Excellent

Braid weaving Fingers are held in extension while packing down weaving

Finger painting Potter s wheel and many minor crafts Fair Motion very light.

Linoleum block printing Fingers flat on block in pressing as, also, in tile setting

Feeding printing press

Holding down plastic or wood as it is cut in a jig saw

To Flex the Proximal Finger Joints and at the Same Time Extend the Distal Two as in Correcting Clawhand.

Flexion of the proximal finger joints is treated separately under that heading and similarly extension of the distal two joints, each joint being treated separately

Distal two joints may be strapped to a flat splint in extension while the proximal joints are being flexed Use of splinting is excellent.

Finger painting Poor

Minor crafts and radio reconstruction Good.

Opposition of the Thumb (Frequently Needed)

Sanding Using block with hole in side for insertion of thumb to be forced into opposition Excellent.

Cutting with scissors material graded in weight Poor because of lack of interest.

Pounding leather graded by weight of leather Fair

Weaving Warping of loom, picking up the threads to be threaded through the needle using warping hook in threading loom. Good motion but of limited application because the looms do not need warping often enough to supply all the needed

PRESCRIPTIONAL GUIDE OF OCCUPATIONAL THERAPY FOR THE COMMONER REQUIREMENTS OF THE HAND

	FINGERS				THUMB	WRIST		
	Flexing proximal finger joints	Flexing all joints	Extending all joints	Flexing proximal and extending distal two for clawhand	Opposition of thumb	Dorsiflexion	Supination	Limbering up hand in general
Carpentry								
Sanding with special blocks	0	0	0	0	0	0		0
Graded sizes of tool handles (Files, chisels, screw drivers, hammers saws)	0	0		0				0
Screw driving					0		0	0
Filing chiseling sanding hammering planing spoke shaving etc.	0	0		0	0	0		0
Clay modeling Potter's wheel	0	0	0	0	0	0		0
Printing								
Type setting		0			0		0	0
Typing		0	0	0				0
Weaving								
Throwing shuttle, beating braid weaving	0	0	0	0	0	0	0	0
Scissor cutting	0			0	0			0
Cutting linoleum blocks	0			0	0			0
Minor crafts								
Basketry	0	0	0	0	0	0	0	0
Cord knotting	0	0		0	0	0	0	0
Leather tooling lacing punching	0	0	0	0	0	0	0	0
Radio construction		0			0			0
Finger painting			0	0				
Gardening	0	0	0	0	0	0	0	0
Recreation sports	0	0	0	0	0	0	0	0

exercise. In weaving the beater of the loom is fitted with a block approximately 4½" x 1½' x 1½" with a groove cut for the thumb and the beater is pulled by this block. This gives both abduction and opposition to the thumb These blocks may be adapted to many deformities so that weaving can be used where otherwise it might not be of value, for example, in radial nerve palsy the blocks can be arranged to correct the ulnar deviation

Type setting Picking up and placing type. Good

Screw driving Good but lacking in interest except in actual construction work.

Writing with pencil built to fit hand Fair

Braid weaving Material used wound in small balls to necessitate grasp between thumb and fingers. Fair

Use of small parts and tools as in radio reconstruction

Minor crafts, etc. See chart. Fair

Dorsiflexing Wrist.

Block printing Inking block with block held at an angle. Good.

Printing Final push on hand lever press gives maximum dorsiflexion of wrist.

Sanding Using flat block and wrist held in dorsiflexion by placing work on a low bench and also on concave surfaces Good

Cord knotting Short strings wound on small blocks of wood pulled tight by dorsiflexion of wrist. Good.

Weaving On large loom beater brought against weaving with beater grasped in dorsiflexion position Good

Spoke shaving Fair

Recreation sports and gardening

Turning small wheel with handle while forearm is braced on a block. (P T)

Minor crafts. See chart.

Weaving on a small loom When changing hand levers dorsiflexes the wrist.

Cord weaving Turning the cord toward oneself and in the beating action.

Supination.

Turning machinery for jig saw, filing, sanding, etc., by turning in rotation T-shaped handles.

Swinging in rotation heavy dumbbell or rod. (P T)

Printing press lever, using it palm up and palm down. Excellent.

Turning a T-shaped handle with axle, placing between two boards screwed together for brake resistance. Good. (P T)

Turning knobs to raise a loom shift in weaving

Using screw driver Screws with left hand thread for left hand Excellent.

Leather thong pulling through holes Poor

Cord knotting Pulling strings tight (stabilization of elbow prevents compensation by elbow movements) Poor because patient compensates too easily and does not give much resistance.

Weaving Throwing shuttle through the shed. Weight of shuttle and material may be graded Poor because it is not resisted motion.

Gardening recreation and other activities. See chart.

To Limber Up and Strengthen Hand in General.

Carpentering involves many procedures giving wide range of varied motions The project may be selected to bring out the finer or the coarser motions

Weaving, clay modeling, gardening, recreation sports, and minor crafts are especially useful

"Hand Ward" Established for Reconditioning of Patients

At the Army Medical Department's Harmon General Hospital, Longview, Texas, the problem of reconditioning patients with hand and wrist injuries is being met with in a novel and unique way All patients with these types of injuries who have reached the stage where some type of exercise is desirable are placed in one ward which is in close proximity with the physical and occupational therapy departments

The ward was organized as a part of the Orthopedic Section under the immediate supervision of the Chief of the Physical Therapy and Occupational Therapy Departments The 'Hand Ward' itself is run entirely by the patients No one needing nursing care is transferred to this ward. All cleaning, bed making, etc., is done by the patients themselves The wardmaster is one of the detachment men who is an artist and experienced in the use of tools

Specific programs are outlined to occupy the entire morning This consists of games, exercises, clay modeling, drawing and painting, and a number of other activities in which the patient must use his hands Appointments for physical therapy are made in the afternoons

The ward is decorated with a number of posters advocating the use of hands, with model airplanes, handmade ash trays, and small hand looms, etc. The solarium of the ward is equipped with a number of small work benches which were made in occupational therapy The open porch is given over to games such as dart throwing pinball machines and others in which the hands are used

To date the ward is working well Formerly it was difficult to keep these patients

active. They apparently felt inferior in their work in the occupational therapy department where they would have to compete with patients with disabilities other than those of the hands and wrists The patients are now contented, they have the responsibility of the operation of the ward Progress is rapid and the various activities of the ward are entered into enthusiastically

The "Hand Ward" idea relieves the routine monotony of treatment and accomplishes the reconditioning of patients of this type in an interesting as well as an educational fashion They do better together as a group, take pride in their accomplishments and convey the idea to newcomers on the ward that much can be done for disabilities of this type.*

Returning Patient to Work. Return to full work immediately following the course in occupational therapy is too strenuous for hands soft from disuse The Birmingham Accident Hospital in England successfully bridged this gap (Gissane and Colebrook) by establishing a building equipped with machinery where the patient is given a job of making the parts which he is able to make. For this he is paid. It was found that repeated motion makes limberness. As the hands became tough, strong and mobile the men were returned to full work.

* Maj Hira E. Branch The Bulletin United States Army Medical Department.

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8

Nerves

NERVE DAMAGE IN WHOLE ARM AFFECTS HAND

The repair of a hand damaged by trauma or whatever other cause usually includes nerve involvement in the problem. In this era of specialization, at the neglect of allied fields, it is beyond controversy that one is not qualified to repair injured extremities unless he has mastered the surgery of nerves. The nerves of the arm and hand in their sensory, motor, and trophic functions are of such vital importance that in dealing with the hand they should be included to as far proximal as the brain. Thus, the hand is directly affected by poliomyelitis, brachial plexus injuries, or trauma to the nerves that course through the arm. From the functional dynamic viewpoint, the hand is controlled by the nerves from the opposite cerebral cortex through the brachial plexus and nerves of the arm. An injury to any part of this pathway may cripple the hand just as much or more than an injury of the hand itself.

Nerves are damaged by trauma such as contusion, severance, explosive force, and overstretching, and by infection primarily even to the degree of sloughing or later from the resulting strangulation by contracting scar tissue. Nerves often injured surgically are the axillary in reducing shoulder dislocations, the radial in operations on fractured humerus, the posterior interosseus in operations on the head of the radius, the sensory branch of the radial and the dorsal branch of the ulnar from incisions for drainage of the forearm, the motor thenar branch of the median from incisions in the palm and the volar digital branches from incisions in a finger or at their fork in the palm. Nerves are commonly cut by lacerations, usually from glass, across the flexors of the forearm just above the wrist, and nerves in the hand are severed by many objects, conspicuous among them porcelain faucets, glass bottles fallen upon, panes of glass, sheet metal, buzz saws, and knives. The incidence of nerve injury in our World War I casualties of extremities was 15 per cent, and half of these were accompanied by fracture.

Purulent infections in the palm and forearm often cause tendons and the median and ulnar nerves to slough from the distal end of the palm to the upper end of the transverse carpal ligament. Infection extends along the median and ulnar nerves in the forearm, leaving behind cicatricial tissue which contracts about these nerves and so impairing the nerve supply of the intrinsic muscles in the hand that from upset muscle balance the position of nonfunction is assumed.

NERVES IN HAND ITSELF *

The nerves in the hand and fingers are important and their repair by surgery is unusually satisfactory. Of all nerve su

* Published in Surg., Gynec., and Obstet., 44 145–152 No 2 1927

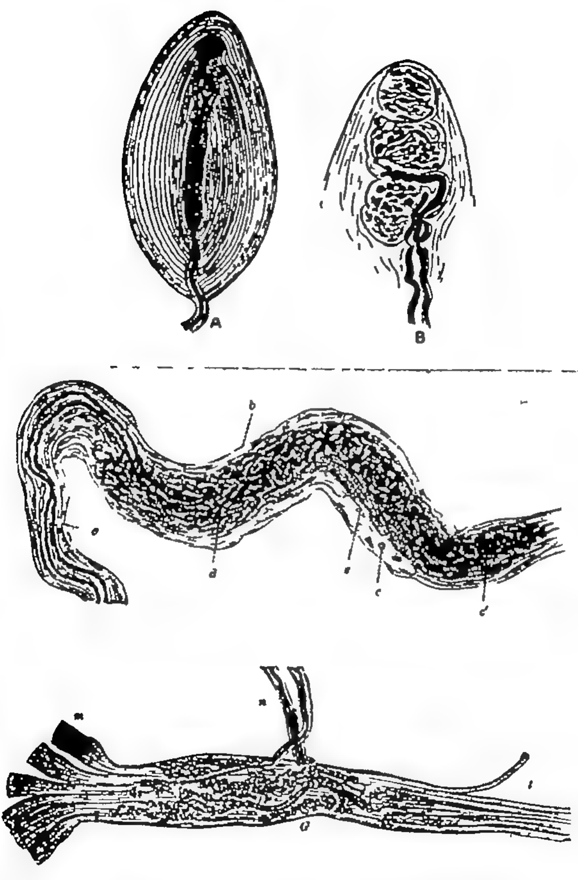


Fig. 273 Special end organs for sensation found in the hand.
(A) Corpuscles of Pacini are conspicuous in the fat yellow 2 or 3 mm. long. (After Ranvier)
(B) Corpuscles of Wagner and Meissner .04 to 15 mm. long plentiful in hand. (After Ranvier)
(C) Organ of Ruffini from the subcutaneous tissue. (After Quain.) (a) Entering nerve fibers (b d) endings of their axis-cylinders (e, c) capsule or organ (c') core size large.
(D) Organ of Golgi in a tendon. (After Quain.) (m) Muscular fibers (t) tendon bundles (n) 2 nerve fibers passing into (G) Golgi's organ. Found in finger pulp and subcutaneous tissues.

tures throughout the body those that are the most uniformly, promptly, and completely successful are those in the hand and fingers. It was, therefore, a surprise to find in 1925 that there was practically nothing

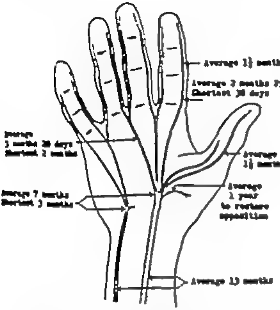


FIG. 274 Diagram showing the average and the shortest time taken in this series, to restore sensation to cotton wool and pinprick over the entire area formerly anesthetic, including the finger tips. The arrows indicate the points at which the nerves were sutured. (Courtesy Surg., Gynec., and Obstet., 44 145 1927)

in the literature on suture of nerves below the wrist. Perhaps the natural presumption was that these were too small to be sutured. At that time I tabulated and reported on the results after repairing 105 nerves of the hand and fingers, largely in the course of operations on the tendons. The fact was then impressed upon me that if the ends of these nerves are accurately approximated very good regeneration always follows. Subsequently, on increasing the series to about 900 the statements made at that time have been well verified.

The exceedingly good results following suture of nerves in the hand are due to two factors. One is that the nerves there are no longer mixed, but are either purely motor or purely sensory The other factor is that the regenerative power of the nervous system increases as we approach the periphery In the central nervous system where there is no neurilemma, axones do not regenerate. In the periphery, however, nerve fibers even penetrate and restore sensation in whole thickness skin grafts

Importance of Function of Nerves in Hand The two major functions of the hand are motion and sensation, and these are of equal importance. Without sensation in the hand, a manual worker is greatly crippled, especially if the area be in the distribution of the median nerve, as this constitutes the principal tactile part of the hand. The pulps of the thumb and first two fingers are particularly important because of their specialized use.

Severance of a volar nerve at the base of a finger results in anesthesia of that half of the finger on its volar surface, and severance of the median nerve in anesthesia of the last one or two distal segments on its dorsal surface. Severance of a digital volar nerve in the palm causes anesthesia in the half of each finger bordering the cleft.

Without sensation, a worker can scarcely pick up a small object, and he constantly drops things from his grasp The so-called eyes of his fingers are blind. He cannot find or distinguish an object with his hand without looking at it. His joint sense also suffers, and he is awkward and fumbles He frequently burns and injures his fingers

The power to oppose the thumb to the fingers is usually lost if the tiny motor thenar nerve is severed, and, if the deep branch of the ulnar nerve is cut, a clawhand results with weakness of the grasp of the thumb and inability to spread the fingers. Although these nerves are small, they are important from a social standpoint, as their loss may cause almost any degree of disability in a manual worker

Atrophic fingers tend to stiffen in the joints and to atrophy in all their tissues until they are reduced to insensitive hooks.

In reconstructing hands, it is best, when nerves to a finger are severed, first to repair the nerves and await good regenera

tion before attempting operations on these fingers or putting tendon grafts in place. In such atrophic fingers wounds do not heal well, and tendon grafts will become adherent and degenerate and will even break.

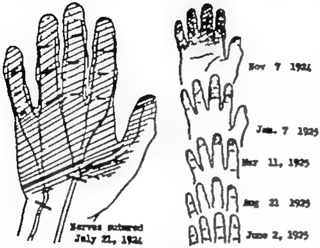


FIG. 275 Case A. L., aged 54 Five months previously a forest bit entered the front of the wrist. This and the infection that followed destroyed all of the tendons and nerves in the front of the wrist. The ends of the ulnar nerve were separated by an inch and the median by 3 inches. Nutrition of the hand was poor On July 21 the two nerves were sutured where indicated and nine tendon grafts from the extensors of the toes were used to bridge the tendons. Anesthesia to cotton wool (shaded) and analgesia to pinprick (dotted) receded as shown by the dates on the diagrams. The power of opposition returned to the thumb as it does in about 66 per cent of repairs by suture of the median nerve. (Courtesy Surg., Gynec., and Obstet., 44 145 1927)

Time of Regeneration. In nerves sutured in the proximal part of the palm an average of seven months was required to restore sensation to pinprick and cotton wool over the entire area formerly anesthetic, including the fingertips. The shortest time was three months. This compares favorably with nerves sutured above the wrist, which in my series required on the average 13 months. Nerves sutured in the distal part of the palm required an average of three months and 20 days, and the shortest time was two months.

In the proximal segments of a finger, the average regeneration time was two months and 25 days, the shortest 38 days, for the axones to grow the length of the finger

In the middle segments of fingers and proximal segments of thumbs the average time was 1½ months Nerves were not sutured beyond the distal crease in the fingers.

As a rule it may be said that sensation after nerve suture of the volar digital nerves is restored at the rate of the length of a finger segment a month. The speed of regeneration in palmar or finger branches is the same for median and ulnar nerves and the same in the thumb as in the fingers.

FACTORS INFLUENCING SPEED OF REGENERATION The cases in this series were checked to determine whether the speed of regeneration were influenced by the length of time between accident and nerve repair This time averaged four months, and in only six did it extend to one year, the longest being four years. The factor of time elapsed was found to have no influence on the speed of regeneration.

The age factor had a moderate influence, in that the ages of the slowly regenerating group averaged 31, of the group of medium speed 25, and of the group of rapid regeneration 21 Age is not of sure prognostic value, however, as some of the old people showed rapid and some of the young slow regeneration.

The factor of greatest influence of all was the state of nutrition of the hand. If the hand had been ravaged by past infection so that congealed tissue resulted in which the cicatrix strangled the nerves, lymph, and blood vessels causing poor nutrition, the regeneration of the nerves was on the average slower and not so complete. Thus, in the group of rapidly regenerating nerves nutrition of the hands was in the proportion of 14 good and four poor In the group of medium speed there were nine good and six poor, and in the group of slow regeneration there were six good and as many as nine poor If we divide out these

fractions—1¼, ⅚, ⅝—we have as the factor that nutrition plays 3 5, 1 5, and 66 for the rapidly, medium and slowly regenerating cases, respectively Therefore, the speed of regeneration was uninfluenced by the length of time between accident and repair, moderately influenced by the age factor, and greatly influenced by the state of nutrition of the hand

Order of Sensations in Regeneration As the nerves of the hand regenerate, sensations are restored usually progressively down the palm and digits Coarse touch advances first, followed by sensation to pin prick. The latter is followed quite closely or accompanied by that to cotton wool touch. Tinel's sign follows down the axones fairly well, and there is usually no tender neuroma left at the site of suture A tingling or tickling paresthesia or hyperesthesia is felt over the area of newly ac-

FIG. 276 Case F R. S., aged 44 Twenty-one months previously the ulnar nerve was severed on a bottle just proximal to its branches, and was sutured on April 2 The dates on the diagram show how the anesthesia to cotton wool (shaded) and analgesia to pinprick (dotted) receded. (Courtesy Surg., Gynec., and Obstet., 44 145 Feb., 1927)

quired sensation This usually disappears after a year or two, although in cases of poor nutrition it may persist longer Occasionally axones become crossed, so that at first the touch sensations of one finger may be referred to another

The trophic effect of a severed nerve commences to leave a finger as sensation is restored, so that in most cases it disappears entirely and the finger throughout its tissues is restored to as near normal as the general condition of the hand allows

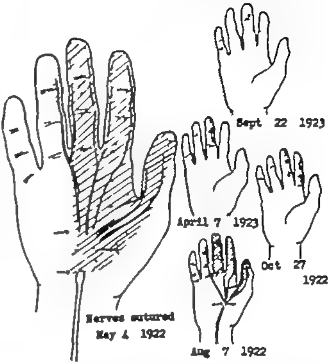


FIG. 277 Case E. C., aged 25 While a bottle was being corked a month previously the glass neck broke and severed two tendons and the median nerve where it branched. On May 4 each of the six branches was sutured to the end of the median nerve. Anesthesia to cotton wool (shaded) and analgesia to pinprick (dotted) receded, as shown by the dates on the diagram. Full ability to oppose the thumb was regained in 11 months through suture of the motor thenar nerve. (Courtesy Surg., Gynec., and Obstet., 44 145 Feb., 1927)

Stereognosis usually returns within a year in the case of sutured volar digital nerves and for nerves sutured in the proximal part of the palm the time averaged 16 months reaching the degree of distinguishing a key, knife, pencil, half dollar, or dime.

Of my series of nerves repaired in the hand almost half were in the fingers and thumb The superficial radial and dorsal branch of the ulnar also were included In one case all eight volar digital nerves were

sutured at the bases of the fingers in one operation with return of sensation throughout, and in many cases the median nerve has been sutured to its six branches. This technic will be described later The deep branch of the ulnar nerve was sutured in 16 cases, and the tiny motor thenar branch of the median nerve is 20 Good function returned to the intrinsic muscles of the hand supplied by these twigs—in the case of the branch of the ulnar nerve correcting clawhand deformity, and of the median nerve restoring opposition of the thumb Thirteen months are usually required for reactivation of these muscles, and improvement continues for several years.

PERIPHERAL NERVES IN GENERAL

Effect of Severance of a Nerve. When a nerve is severed there results an area not only of loss of touch, pain, and muscle sense but also stereognostic sense and defense against injury From motor paralysis the muscles affected atrophy, and their opponents draw the limb into deformity From loss of trophic supply there is atrophy of all tissues from skin to bones and joints *The nerve above the severance* does not swell unless it becomes infected. Its axones split up into many times their normal number and attempt to grow down to rejoin the nerve. Connective-tissue growth, however, precedes them, capping over the end of the nerve. The axones grow into this, many of them turning on themselves and ending in a snarl, while others escape out into the tissues so when the tissue is tapped with the finger tingling is produced. Thus, a bulb-like neuroma terminates the upper portion of the nerve. The lower portion commences on the first day to swell with Wallerian degeneration which is complete in a month The nerve remains swollen about twice its size. Its end either becomes tapering or shows a small enlargement which, contrasted with *the neuroma of the other end*, is a glioma of connective-tissue elements. The connective-tissue growths from each end may meet each other, if the nerves are not too far apart, in a natural attempt to rejoin Some

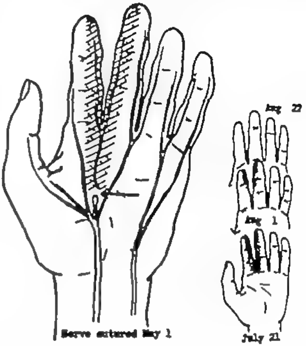


Fig. 278 Case E. P., aged 31 Sixty five days previously the palm of the hand was lacerated on a milk bottle and the tendons and one of the volar digital nerves were severed. The nerve was sutured on May 1 and by the dates on the diagrams is shown the recession of the anesthesia to cotton wool (shaded) and analgesia to pinprick (dotted) (Courtesy Surg., Gynec., and Obstet., 44 145 Feb., 1927)

of the multiplied axones may cross the gap and grow down the terminal segment of the nerve, thus restoring its function to some degree if the nerve gap and scar tissue are not too great.

Symptoms of Nerve Injury Through association we should learn the nerves by the areas they supply with sensation and by the motions they control.

Sensory The hand is a sense organ. In its skin and in the pulp of digits and palm are several kinds of specialized touch corpuscles Pacini's, Ruffini's and Meissner's. The area supplied by the median nerve is most acute, especially the pulps of the thumb and first two fingers. Linked with the stereognostic center in the opposite side of the brain, it is this area of skin which is

most specialized to give sense of texture and shape. Thus, in median nerve paralysis the manual worker is greatly handicapped.

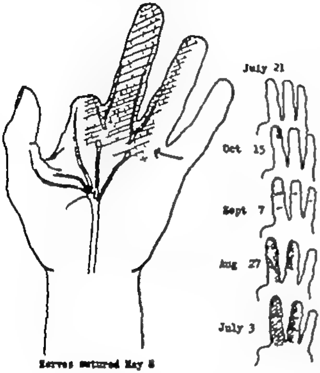


FIG. 279 Case D B., aged 47 Seven months previously a buzz saw cut across the distal part of the palm. Two volar digital nerves in the palm were sutured, and the anesthesia to cotton wool (shaded) and analgesia to pinprick (dotted) receded, as shown by the dates on the diagrams. (Courtesy Surg., Gynec., and Obstet., 44 145 Feb., 1927)

Sensibility is superficial or deep according to whether its end organs are in the integument or deep in the muscles, tendons, and joints. By the first we detect touch compass points, temperature, and pain, and by the second muscle and joint movements and position, deep pressure, and vibration Deep sensibility travels mainly in the motor nerves and is of wider distribution than superficial, some remains even when all skin nerves are cut.

Superficial sensibility may be divided by degree, as when recovering from anesthesia we first detect protopathic or coarse sensations pain, touching hair coarse pressure, and wide differences in temperature, and later gain the finer epicritic sense light touch, compass points, and narrow ranges of temperature Stereognosis is interpreting shape by protopathic sense and texture by epicritic, in recovery it is the last to return It is tested by identifying with eyes shut an object placed in the hand and by recognizing letters or numbers drawn by a point on the pulp of the digits.

From a practical working standpoint it is usually sufficient to map the areas for light touch, coarse touch, and pinprick, using a cotton fluff on one end of an applicator and a needle on the other For light touch the applicator is held delicately between the thumb and index finger with just enough of a stroke to be felt on normal skin, for coarse touch the pressure is greater Starting in the anesthetic area and radiating outward to normal skin, the patient with eyes closed announces each time he feels, and a mark is made on the skin If one desires to ascertain degree of touch sensation, one can use several graded spring wires with a millimeter size contact point at the end, and for grading degree of pain, a pin with the gram pressure regulated

A method of mapping anesthetic areas is by an electric skin resistance machine consisting of a 4½ volt battery, a microammeter, and two electrodes placed near together Anesthetic skin is electro-resistant as the sweat glands are dry Placed on normal skin this apparatus is a lie detector and is excellent for malingerers who claim pain, as telling a lie or feeling pain causes sweating, thus good conductivity and definite indication by the galvanometer Loss of sweat function and sense of touch do not always coincide, the former being usually wider

MOTOR. A muscle supplied by one nerve is completely paralyzed on severance of that nerve It commences to atrophy and this is quite conspicuous after three months. Increasing progressively, in a year or more it is extreme. Gradually the muscle undergoes fibrous degeneration, until after several years most of the muscle will have turned to fiber When muscle

groups are paralyzed, the opposing muscles are free to draw the limb unresisted into the opposite posture, until extreme deformity may result. The opposing muscles gradually contract and become permanently so, and secondarily, all of the other tissues on the contracted side share in the general flexion contracture, so the limb cannot be placed in its normal position.

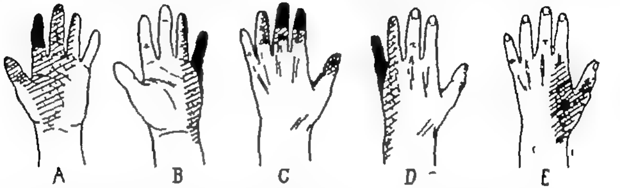


Fig. 280 Average areas of sensory disturbance after severance of each of the three main nerves to the hand (*Shaded*) Anesthesia to light touch (*Dotted*) analgesia to pinprick (*Black*) total anesthesia or isolated supply
(A) Median nerve, volar surface
(B) Ulnar nerve, volar surface
(C) Median nerve dorsal surface
(D) Ulnar nerve, dorsal surface
(E) Radial nerve May be no isolated supply

When a muscle is only partially paralyzed, as from a partially injured nerve or involvement of only part of its double nerve supply, we must seek finer signs for diagnosis. The feel of the muscle belly will be less resistant as will that of the aponeurosis overlying the muscle and the tendon of the muscle. Slight action may be detected by palpation over muscle belly or tendon. Though insufficient in strength to move a limb, a muscle may momentarily hold it in the position placed A tenometer, indenting a paralyzed muscle, may measure in millimeters of mercury pressure only one-third to one-fourth that of a normal muscle but this is unreliable. The tone of the muscle is also shown by some resistance to passive movement in the other direction. In seeking for slight voluntary motion we should first eliminate gravity by making the axis of the joint vertical or by hanging the limb vertically downward and then requesting the movement from the patient. Lessened nerve supply is shown by limited amplitude of motion by the muscles and by limited endurance or early exhaustion, by lessened force and by decreased skill All of these tests apply to flaccid paralysis from injury of the lower neurone in contrast to spastic from the upper Reflexes through the paralyzed nerve are diminished or lost.

Electrical Reactions. Following severance of a nerve by three or four days the muscles will no longer react to any electrical stimulation of the nerve. The muscle may be stimulated directly by faradic electricity until in from four to seven days the reaction of degeneration commences. This reaction is not complete until two weeks. It consists of absence of reaction to the faradic current but to the galvanic the reaction is greater in amplitude, slow and vermicular, and followed by slow relaxation. The muscle shows this type of reaction until from fibrous degeneration it reacts no more.

Each muscle has a point at which it responds best electrically, usually this is where the nerve enters it. As the reaction of degeneration is leaving after two years, the last of it to go may be obtained by

FIG. 281 Frostbite of fingers incurred on army post while waiting for a bus. The median and ulnar nerves have been severed.

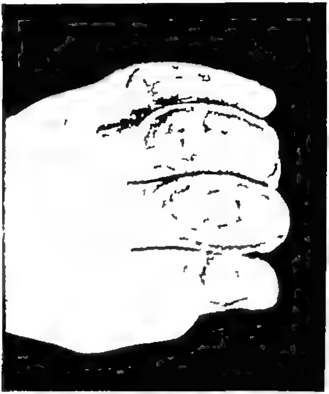


FIG. 282 Accidental burn by heat lamp in case of high nerve paralysis.

longitudinal stimulation with a pole at each end of the muscle.

Normal muscle reacts well to the faradic current, and through its fibrillary element gives a quick twitch to the galvanic. Normally, stimulation of the nerve causes great reaction.

TROPHIC SYMPTOMS. From loss of nerve supply the part affected atrophies in all its tissues from skin to bone. The greatest atrophy is found in the painful, irritative lesions in nerves. The atrophy of a limb as a whole can be measured by the amount of water displaced on immersing it. The skin in an anesthetic area is so characteristic that one can, by feeling with the finger, determine the area almost as accurately as by testing with an applicator. The finger glides over it smoothly with a satiny feel, it does not jump along as it does on normal skin in which the sweat glands are working. Atrophic skin appears smooth. The rugae of finger prints disappear and the color is red or slightly cyanotic. The skin may thicken from lack of desquamation and cracks from loss of elasticity. The glossy, bright red skin is seen more often in irritative lesions.

Hair may become brittle and drop off, or may be long and thin. Nails are of poor quality, thick, brittle, and with decreased growth; they show transverse and longitudinal ridges, lateral arching and discoloration. In muscles undergoing atrophy the weight may be reduced one-third in the first two weeks. Finally, when well atrophied, there is instead of the usual convexity conspicuous and deforming concavity. The bones lose their calcium, becoming soft and osteoporotic, joints show thinning of cartilage, contraction and loss of flexibility of ligaments, resulting in decrease of movement even to adhesions in the joint and ankylosis. The anesthetic parts, especially the digits, are subject to injury, particularly from burns. Healing is slow and the wound is repeatedly injured.

Trophic changes from loss of nerve supply should be differentiated from those due to lessened blood supply. Vessel injury

alone gives lowered nutrition, but frequently there is superadded a reflex dystrophy or vasospasm The latter, from *severance of an artery, is characterized by* hard, inelastic induration, swelling, edema,

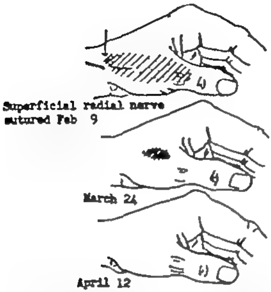


FIG. 283 Case C. M. S aged 49 Six *months previously a knife severed the* short extensor tendons of the thumb and the superficial radial nerve. The tendons and nerve were repaired on February 9. On March 24 he could feel pinprick (dotted) throughout, and on April 12 could feel cotton wool (shaded) throughout. (Courtesy Surg., Gynec., and Obstet., 44 145 Feb., 1927)

cold cyanosis a purplish red, bluish black color and gushes of blood if pricked.

Severe injuries of brachial plexus and multiple nerves in the arm cripple hands. If neglected, there is the usual position of non function, flexed or straight wrist, straight proximal finger joints, flat palm and thumb at the side. All tissues are atrophic and withered from disuse. There is stiffening of the joints and cyanosis If, in addition, there is arterial damage, the condition is much exaggerated. There may be Volkmann s ischemic contracture in forearm or locally in the intrinsic muscles of the hand and amputations of the tips of several digits from gangrene In these cases the whole hand is hard and stiff Sympathectomy is beneficial.

A discussion of irritative nerve lesions and trophoneuroses may be found in Chapter 17

Location of Lesion Frequently persons seek consultation for an ailment in the hand whereas the causative lesion is in the brain, spinal cord, nerve roots, brachial plexus, or in the peripheral nerves of the upper extremity

The following classified findings may be of aid as a quick working summary in differential diagnosis, though with practice diagnosis comes almost instinctively

CEREBRAL. *Absence* of sensory disturbance, electrical reactions normal, no atrophy, spastic not flaccid paralysis, pattern does not fit cord lesion.

CORD Flaccid paralysis at the lesion and spastic paralysis below it. Irritative phenomena may be present from the segment just above the lesion, such as clawhand from first dorsal paralysis. Long sensory and motor tracts passing the lesion may also be affected, thus showing signs below the level.

Intramedullary lesions may show loss of temperature and pain sense, these fibers crossing at the dorsal canal, but preserve tactile sense. In a cord lesion the distribution to the upper extremity will be segmental, instead of in accordance with *peripheral nerve distribution*, as shown in Fig 284 Segmental sensory areas parallel each other longitudinally down a limb, starting with the fifth cervical in the radial area of the upper arm and ending with the second dorsal in the ulnar border of the upper arm. Sensory distributions by nerves are much more blocked out in areas, as shown in Fig 284 As regards both sensation and motion, *each cord segment or spinal nerve supplies* several peripheral nerves. Thus, the sensory areas of two spinal nerves overlap one-half, and it is necessary that both of these nerves be injured before any anesthesia results. For this reason the upper limit in the cord or spinal nerve is always one segment higher than the anesthesia indicates. The

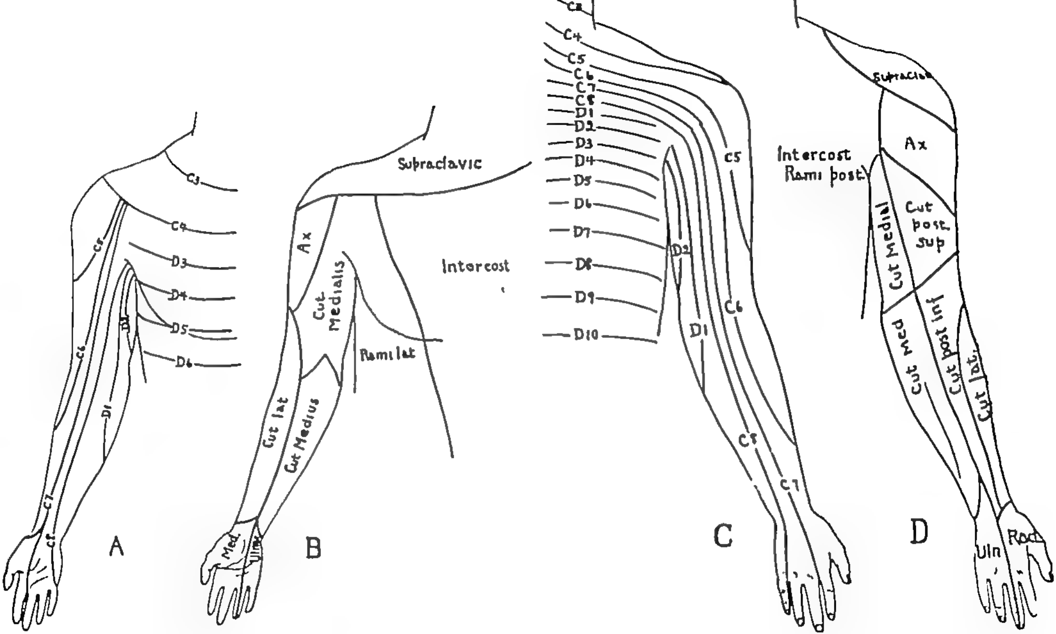


Fig. 284 (A and C) Sensory distribution in upper extremity according to caudal segments. (B and D) Sensory distribution in upper extremity according to nerves. (After Bing.)

SEGMENTAL INNERVATION OF MUSCLES OF UPPER EXTREMITY

	Cervical Segments				*Dorsal Segments*
	5	6	7	8	1
Shoulder	Supraspinatus				
	Teres minor				
	Deltoideus				
	Infraspinatus				
	Subscapularis				
	Teres major				
Arm	Biceps				
	Brachialis				
		Coracobrachialis			
			Triceps brachii		
			Anconaeus		
Forearm	Supinator longus				
	Supinator brevis				
	Extensor carpi radialis				
		Pronator teres			
		Flexor carpi radialis			
		Flexor pollicis longus			
		Abductor pollicis longus			
		Extensor pollicis brevis			
		Extensor pollicis longus			
		Extensor digitorum communis			
		Extensor indicis proprius			
		Extensor carpi ulnaris			
		Extensor digiti V proprius			
			Flexor digitorum sublimis		
			Flexor digitorum profundus		
			Pronator quadratus		
			Flexor carpi ulnaris		
			Palmaris longus		
Hand		Abductor pollicis brevis			
		Flexor pollicis brevis			
		Opponens pollicis			
				Flexor digiti V brevis	
				Opponens digiti V	
				Adductor pollicis	
				Palmaris brevis	
				Abductor digiti V	
				Lumbricales	
				Interossei	

segmental distribution of enervations of muscle are roughly as follows

C 5—shoulder
C 6—upper arm
C 7—wrist, forearm
C 8—fingers
D 1—intrinsics of hand

Table on opposite page shows reflexes by segments. (Bing)

In motor function, segmental versus peripheral nerve pattern of distribution is commonly seen in the following examples

In median and ulnar nerve palsy all the flexor muscles in the forearm will be paralyzed, but from paralysis of C 7, C 8 and D 1 spinal nerves there will still be some function from the sixth cervical nerve in

the flexor carpi radialis, pronator teres, and flexor pollicis longus Paralysis of the deltoid and teres minor from the circumflex nerve could not occur in segmental injury, as the biceps, supinator longus, and scapular muscles are also furnished by C 5 and C 6 segments and would share in the paralysis. In paralysis of the radial nerve, all extensors in the forearm will be paralyzed, including the supinator longus, but in segmental paralysis the supinator longus may be spared, as it is supplied by one spinal nerve higher, namely, C 5

Reflexes are lost when the reflex arc is obstructed. They are easier to elicit in young people. Those commonly recognized are as follows (After Bing)

REFLEXES IN UPPER EXTREMITY

Tendon and Bone Reflexes	*Skin Reflexes*	*Method of Starting*	*Effect*	*Localization*
1	Scapular reflex	Stimulation of the skin over the scapula	Contraction of shoulder blade muscles	C 5—D 1
2. Biceps reflex.		A blow on the biceps tendon	Flexion of forearm	C 5—C 6
3 Triceps reflex.		A blow on the triceps tendon	Extension of forearm	C 6—C 7
4 Scapulohumeral reflex.		A blow on the inner side of the lower angle of the scapula	Adduction of arm	C 6—C 7
5 Radius reflex		A blow on the styloid process of the radius	Supination of forearm	C 7—C 8
6.	Palmar reflex	Irritation of the palm	Flexion of fingers	C 8—D 1

After injury to C 8, D 1, and D 2 segments or their nerve roots, the effect in the arm will be accompanied by Horner's syndrome, consisting of contraction on that side of the pupil, narrowing of the palpebral fissure and recession of the eye.

A protruding disc between C 4 and C 5 compresses C 5 root. To locate position of cord segment from C 2 to T 10, add two to the spinous process

BRACHIAL PLEXUS The brachial plexus commences with five spinal nerves which as they pass over the scalenus medius muscle fuse, in the supraclavicular fossa, to three trunks, the middle one of which is from the seventh nerve only All the nerves to the extensor muscles of the limb then branch off from the trunks as the posterior division The divisions, which are behind the middle third of the clavicle to outer border of first rib, group themselves into an outer, a posterior, and a medial or inner cord, according to their locations about the subclavian artery and distribution down the arm The outer is all for flexor and pronator motions and the posterior all for extensor and supinator motions from trunk to fingers The inner cord is for flexor muscles on the extreme ulnar border of the forearm and the intrinsic muscles in the hand, and these have, in addition to flexor motions, some extensor action in the distal two finger joints.

These three cords, which are in the axilla, then divide into the peripheral nerves. The outer cord branches to the musculocutaneous for flexing the elbow and to the upper branch of the median nerve for sensory distribution, for flexors of the wrist, and for pronators The posterior cord supplies the shoulder and continues as the radial nerve The inner cord branches to sensory nerves down the inner side of the arm, to the ulnar nerve and to the lower branch of the median nerve for flexors of the digits.

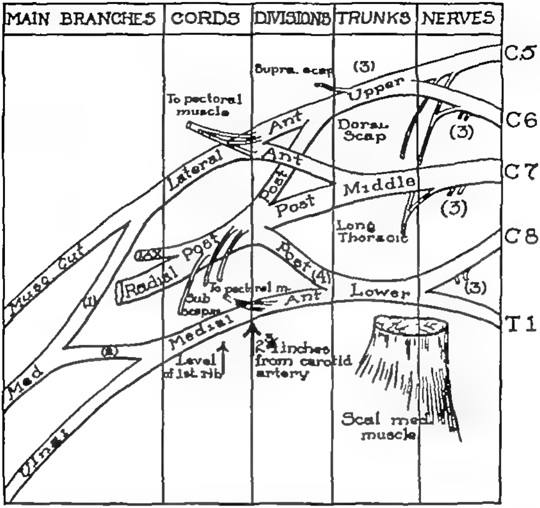


FIG. 285. Schematic brachial plexus as an aid to diagnosis. The order and level of the departure of the nerves from the plexus is indicated.

(1) Pronators of forearm and flexors of wrist.
(2) Flexors of fingers and median intrinsic muscles of thumb.
(3) Supraspinatus, deltoid, biceps, brachialis, supinator longus and (1)
(4) Extensors of fingers.

In medial cord are flexors of digits and all intrinsic muscles of hand. The first nerves to leave the plexus penetrate the scalenus medius muscle behind and are the dorsalis scapulae for levator anguli scapulae and both rhomboids, long thoracic for scalenus anticus and muscular branches (short) for scaleni and longus colli. Involvement of the scalenus level indicates a high lesion usually avulsion from the cord.

Trunks are in supraclavicular fossa distal to scalenus medius.
Divisions are behind middle third of clavicle.
Cords are in axilla commencing at outer border of first rib

The lesion can be placed longitudinally in the plexus by checking on the nerves in their order of leaving the plexus. As the spinal nerves change to trunks on traversing the scalenus medius muscle, two nerves leave the upper part of the plexus and penetrate this muscle, they are the dorsal scapular to the levator anguli scapulae and rhomboideus muscles, and the long thoracic to the serratus anterior. If, in upper plexus palsy, these muscles are not functioning after a year, the spinal nerves have been torn in the foremena or from the cord and are irreparable.

The next nerve leaves the plexus at the level of the trunks, it is the suprascapular to the supra and infraspinatus muscles. Leaving the posterior cord are the three subscapular nerves, which are internal rotators and depressors at the *shoulder, in contrast*

to the external rotators and elevators which left the plexus earlier from the trunk by the suprascapular nerve At the next level at the termination of the cords all of the remainder of the nerves leave the plexus, including the axillary

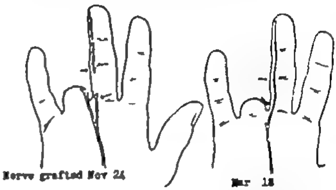


FIG. 287 Case H D N., aged 36. Sixty nine days previously a steam-shovel amputated the ring finger and removed a segment of the volar nerve from the ad joining side of the long finger On November 24, the three-quarter inch gap in the nerve of the long finger was bridged by a free graft (shown in solid black between the arrows) from the volar nerve of the amputated finger Anesthesia to cotton wool (shaded) and analgesia to pin prick (dotted) left the long finger in four months. (Courtesy Surg., Gynec., and Obstet., 44 145 1927)

Some additional diagnostic points follow

A lesion of the outer cord differs from one of the fifth and sixth roots inasmuch as the shoulder muscles, including the deltoid and the supinator longus, are spared. Also with the outer cord the pronator teres and the radioflexors of the wrist which come from the seventh cervical are paralyzed

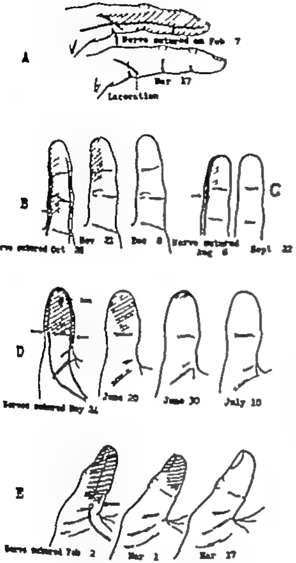


FIG. 286 (A) Case J B H., aged 30. Eighteen days previously the volar nerve on the radial side of the index finger was severed with a chisel. It was sutured on February 7 and on March 17, only 38 days later cotton wool and pinprick could be felt over the entire area which had been anesthetic.

(B) Case J C., aged 21 Four months previously the volar nerve on the ulnar side of the index finger was severed with a knife. The nerve was sutured on October 28. The area insensitive to cotton wool (shaded) and pinprick (dotted) receded, as shown by dates on diagram.

(C) Case E. C., aged 16 Three months previously one volar nerve of the long finger was cut by an electric fan. The nerve was sutured on August 8, and 45 days later cotton wool and pinprick could be felt over the area of the pulp which had been anesthetic.

(D) Case J L., aged 28 Three months previously both volar nerves of the thumb were cut with a knife and the pulp of the thumb became anesthetic and interfered with patient's work. The nerves were sutured on May 24 and the anesthesia to cotton wool (shaded) and analgesia to pin prick (dotted) receded, as shown by the dates on the diagram.

(E) Case G A. J Six months previously the volar nerve on the radial side of the thumb was cut on a glass jar and the important tactile area of half the pulp of the thumb rendered insensitive. The nerve was sutured on February 2 Anesthesia to cotton wool (shaded) and analgesia to pin prick (dotted) receded, as shown by the dated diagrams.

(Courtesy Surg., Gynec., and Obstet., 44 145 1927)

In paralysis of the seventh cervical nerve, the supinator longus and deltoid are spared because they are innervated by the fifth and sixth cervical The coracobrachialis

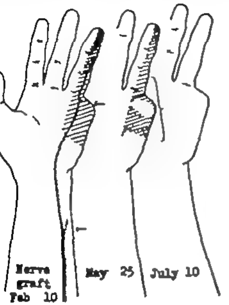


Fig. 288. Case J K., aged 26. Eight months previously the wrist was lacerated on a windshield and a severe infection followed, necessitating amputation of the little finger As a length of the ulnar nerve had sloughed, a strand of sural nerve from the leg was used as a six inch graft to bridge the ulnar nerve, as shown in black between the arrows in (A) on February 10 Three and one-half months later coarse touch could be felt opposite the bracket in (B) and the area insensitive to cotton wool (shaded) and pinprick (dotted) had reduced in patches. In five months these sensations could be felt throughout, as in (C) and in ten months after the nerve suture enough stereognosis had returned to distinguish a cotton applicator a piece of gauze, and a piece of metal, though he could not differentiate between a coin and a key (Courtesy Surg., Gynec., and Obstet., 44 145 1927)

muscle is paralyzed, though not from injury to the fifth and sixth cervical nerves When the posterior cord is not working the deltoid and teres major are paralyzed, though they are spared in paralysis of the seventh cervical nerve. When the eighth cervical and first dorsal nerves are out there is paralysis of all of the intrinsic muscles of the hand, together with all flexors of the digits. Paralysis of the inner cord differs in that flexors of those fingers and thenar muscles which are supplied by the median nerve are not involved.

Though the brachial plexus may be injured directly by stab or gunshot wounds, it is usually the result of traction. By traction the plexus may be damaged anywhere from the cords to avulsion from the spinal cord, as further detailed in Chapter 11 Any of the three cords may be involved If the arm is pulled downward away from the head the upper two or three spinal nerves are parted, but if the arm is pulled upward the eighth and first and sometimes the seventh give way and the whole plexus may be paralyzed. In adults or at birth from traction we commonly see the upper nerves involved, called Erb-Duchenne paralysis, in which the arm hangs at the side in internal rotation and the head of the humerus dislocates backward on the scapula, and less commonly we see involvement of the lower trunks in Duchenne-Aran or Klumpke's palsy Here the forearm and hand muscles are paralyzed and the hand is flat and useless. Usually some of the flexor carpi radialis, the pronator teres, and the flexor of the thumb from C 7 are spared. For plexus injuries other than diagnosis see Chapter 11, The Arm in Its Relation to the Hand.

Peripheral Nerves Having outlined the area of anesthesia and analgesia and by survey having found which muscles are paralyzed or partially so and the areas of anesthesia, then assuming that brain and cord injuries have been ruled out, the lesions along the involved nerves are further located by the history of the accident, by the location of the scar, and by Tinel's sign. The latter, which is tingling on tapping over the severed or injured nerve ends is quite reliable, accurately pointing out the location of the lesion. After partial regeneration Tinel's sign can also be elicited

distally down the nerve as the new axones grow Further details are given under the heading for each nerve.

FUNCTIONAL ANESTHESIA AND PARALYSIS The area of anesthesia is not anatomic in accordance with either segments or nerves, and its boundaries vary with each examination. The distribution is generally glove-like or spread over a flexor or an extensor surface irrespective of the nerves Patients with eyes closed often answer "no' as well as 'yes" each time they are touched. Reflexes and electrical reactions are normal and there is absence of atrophy In imitating paralysis they make no effort at all to move the limb Often when their hand is placed in a position they will hold it so There are no burns in the anesthetic areas A peculiar posture of the hand may be assumed and maintained The condition is often accompanied by osteoporosis, contractures, and vasomotor signs such as cyanosis, cold sweat, and macerated skin

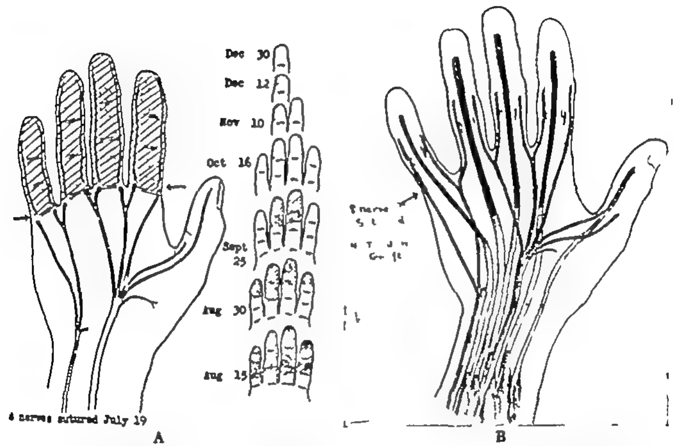


FIG. 289 Case J T aged 25 Forty-two days previously the hand was caught under the sharp edge of a large rotating pipe and every flexor tendon and every volar nerve was severed at the base of each finger and the fingers were rendered useless. The eight volar nerves were sutured on July 19 Their ends were approximated by flexing the fingers. The anesthesia to cotton wool (shaded) and the analgesia to pinprick (dotted) receded, as shown by the dates on the diagrams.

(A) On December 15 the remains of all the flexor tendons were removed from the four fingers and in their places free grafts of the sublimus tendons were used to prolong the profundus tendons to the ends of the fingers. (Courtesy Surg Gynec., and Obstet., 44 145 Feb., 1927)

(B) This operation had to be delayed until the nerves had regenerated or else it would have failed from lack of trophic supply Good sensation and motion were obtained in each finger Eventually the fingers could flex almost to the palm (Courtesy Jour Bone and Joint Surg., 10 1 No. 1 1928.)

Degree of Lesion. Unless from the nature of the accident the nerve must be severed, there is no way of determining by symptoms whether a nerve is physiologically or anatomically interrupted. We diagnose only between complete and incomplete lesions, meaning nerve blocks. This is

important for prognosis and decision for operation.

In a complete lesion we find the following complete paralysis of all muscles, complete anesthesia in isolated supply, reaction of degeneration progressively increasing, rapid and great atrophy Pain is not elicited by pressure on nerve trunk, muscle, or by pinching the anesthetic skin. Unnatural cold, a dry sweatless feel to the skin, progressing R. D, and rapid onset of atrophy are quite sure signs, though marked atrophy is unreliable as it is greatest in painful or incomplete lesions

Incomplete lesions are characterized as follows

There is pain on pressing the nerve below or the muscle, or on pinching the skin, though absence of pain on muscle pressure is unreliable. Tinel's sign is present below Formication occurs on touching below the lesion. Sensation to touch or pinprick is present in isolated supply Sweat may be present.

In complete lesions, hyperesthesia may occur when sensation to pinprick has returned to the area of overlap, and should not be misleading Motor function is more vulnerable than is sensory Muscle tone is unreliable, so are trophic changes unless they occur rapidly Often one must wait several months to be certain whether a lesion is complete or incomplete. If the signs of complete lesion persist for five months one can be practically certain of the completeness.

Prognosis. In the majority of cases of nerve injury spontaneous recovery follows. Severed nerves will bridge a short gap of 1 cm. or a little more, but the longer the gap the less will be the recovery Contused nerves that retain their continuity recover, but those left strangulated by cicatrix do not, unless aided by surgery If a limb postoperatively is splinted in such a position that a nerve is on a stretch, that nerve will become paralyzed for from a month to permanently A nerve at operation stripped of its surrounding tissues for a length of many inches will often not function for three or four months, because that segment left without blood supply, except from the nerve itself, acts more or less like a nerve graft.

Recovery after nerve suture expressed in percentage is difficult to ascertain because of the multiple factors that determine the result, namely, the length of the gap the amount of cicatrix, the state of nutrition, the time elapsed since injury, the criteria of success, and the way the nerve suture was done. Therefore, we have varying statistics, such as the following

Of 1,500 cases by four operators, there was reported 50 per cent recovery after suture and 80 per cent after neurolysis. Another compilation of 21 authors gives 60 per cent good results, but the good results range with the different operators from 22 to 96 per cent.

From a personal series of 1,343 nerve repairs, about 900 of which were in the hand and digits, it is clear that the conditions found and the accuracy of repair determined the quality of regeneration. Assuming that the nerve has not been injured for any length, that the state of nutrition is good, that not enough time has elapsed for fibrous degeneration of the muscles, and that in the postoperative course the nerve in which there was a large gap has not been stretched out too rapidly, we may be sure that the degree of recovery will be in direct proportion to the accuracy of the union.

This includes exact axial rotation. Any error of rotation will result in sensory axones growing down motor pathways, and vice versa, so each will be wasted Nerve bundles should be properly matched and apposed exactly together without intervening scar tissue. The sheath should be so accurately joined that no axones will escape

into the surrounding tissue but all grow on down the nerve.

The nerve should then regenerate at the rate of 1 or 2 mm a day It will require a long time if sutured high in the arm but eventually sensation usually occurs throughout, or with the exception of some finger tips, and most of the muscles should regenerate. Fairly often some of the terminal muscles will not, such as the extensors of the thumb or the intrinsic muscles in the hand. Sometimes certain individual muscles will be left out, due to axones not growing down the pathways of their nerve branches. In many cases nerves that have been sutured high in the arm have made such good recovery that the disability is hardly noticed. If the lesion is high, the exploration for operative repair must be rushed, instead of postponed to see what recovers, because axones take so long to grow down the arm that muscle atrophy may progress too far Also, the longer the time elapsed since the accident, the slower will be the rate of recovery

When a nerve is sutured high in the arm the first signs of improvement may not be seen until four or five months later, at which time the proximal border of the anesthetic area will start to recede. Soon the muscles nearest to the suture line will commence voluntary motion in order down the limb as the axones progress By ten months or a year sensation and motor function will be fairly well along, though the degree of regeneration will not be at its maximum until from three to five years. If five or six years have elapsed since the nerve severance sensory recovery can still be expected, but after two or three years at the most the degree of motor recovery will not be great. Its degree can be roughly prophesied by the size of the reaction to the galvanic current which is still present in the muscles. When sutured even as late as 11 years after the accident I have seen a slight voluntary flicker return in the case of a radial nerve, though not of any practical benefit. The sooner a motor nerve is repaired, the better will be the regeneration as fibrous atrophy is progressive in muscles from the time of the accident. Ruth Bowden and Guttman studied biopsies of human nerve and muscle in nerve lesions and stages of recovery They demonstrated histologically what limits recovery In denervated muscles the wavy crosslines become dotted, connective tissue increases and finally all muscle goes, and the process becomes irreversible Up to three years, there is no degeneration or disruption, but enough shrinkage of muscle occurs and connective tissue proliferation to limit recovery after enervation. They found muscle atrophy in one to three months to be slight, in three to 12 months to be moderate, one to three years considerable and over three years to be extreme Degeneration in nerves is progressive. Axones go, collagen increases and Schwann's tubes become so narrow and blocked by connective tissue that the axones cannot penetrate Motor fibers, which are larger, are first blocked and later the sensory axones, which are thinner Sutured nerves, when recovering show at first thin, non myelinated axones passing through the Schwann's tubes, then thicker and with degrees of myelinization Some end plates begin functioning again, and, also, some new end plates are formed Regeneration depends also, on the degree of nerve lesion (Seddon) If the nerve were disrupted (neurotomesis), some axones after suture would follow down wrong pathways so recovery would be less If the axones were disrupted, but the nerve structures were intact (axonotemesis), axones would grow down proper pathways and recovery would be rapid and to good degree If there were merely attrition and the axones blocked but not disrupted (neuropraxia) the recovery would be rapid and complete

Nerves sutured primarily under proper conditions of débridement and accuracy make a faster and more complete recovery than do nerves sutured later Delaying su

ture a few weeks, with the idea that one cannot tell at first how far back axones will degenerate from the trauma, is of no advantage. In either case, primary or secondary suture, the axones must be cut across If the trauma has been excessive one can allow for it and cut back further Nerves which are torn apart give the worst results This is because while they are under tension the axones keep breaking over quite a length of the nerve until the nerve finally is torn apart at one place It is like a large rope which has been pulled apart. For the length of several feet one can see the fuzzy ruptured strands projecting from the body of the rope, and there is a tuft of fibers projecting at each rope end. Even at that when sutured, *there will be some degree of* recovery (See Fig 479)

In the arm, the radial nerve recovers after suture better than does the median, and the median makes a better recovery than the ulnar This is apparently because the radial nerve is composed mostly of motor fibers, while in the ulnar the sensory and motor fibers are more equal in number Thus, some fibers are wasted by growing down the wrong pathways.

In the beginning of this chapter it has already been described how wonderfully well the nerves sutured within the hand recover

Mode of Recovery Following suture of a nerve or freeing a completely blocked one there is return of sensation, motion, and trophic supply in a rather uniform manner

Sensation Sensation returns before motion and in a rather serial way, the proximal portions of the anesthetic area disappearing first, sensation progressing down the limb until it includes the tip Recovery to coarse touch and pinprick precedes light touch. *Protopathic precedes* epicritic. Deep sensibility returns with epicritic sense and finally, as a composite interpretation, stereognostic ability is acquired. A very early sign of recovery is *pain elicited by pinching the skin* in the area where it is absent in a complete lesion namely, in the isolated nerve supply This sign may precede Tinel's sign An early sign seen a little later is pain, ache, or formication, elicited on pressing the nerve below the lesion Another early sign is an ache or a mean feeling on pinching the muscle which has been paralyzed Finally, before real touch sensation is established, formication is felt on touching the skin

Tinel's sign is very valuable, and contrary to statements I have found it to be reliable when one blocks with one hand all tissue proximal from vibrating It consists of tingling on tapping The tingling is referred *to the normal area of distribution of* the nerve. Following severance of a nerve, the sign appears in a month to a month and a half, just when the axones have had time to grow from the nerve end out into the surrounding tissues In three months from severance Tinel's sign may be so extreme that there is troublesome hyperesthesia on tapping the neuroma. Following nerve suture or the freeing of a completely blocked nerve, the tingling on tapping can be elicited anywhere over the new down growing, nonmyelinated axones. It persists *for a year or two and finally disap*pears as the axones become myelinated To avoid false interpretation, one hand should be pressed against the skin between the nerve juncture and the point being tapped, so as not to elicit the tingling from that site. Tinel's sign is always more marked when a nerve is actually severed than when merely damaged, as it indicates new free axones

Following severance of a nerve there is always, in several months, some recession of the area of anesthesia except in the *isolated area for that nerve*. This is from overlap of surrounding nerves and should not mislead us to interpreting it as regeneration Overlap may be determined by disappearance if we block with novocain

the overlapping nerve. With eyes closed the patient will localize a pin prick accurately if due to overlap (Shreve), but due to scattering of axones he will localize it in wrong places, if it is a case of regeneration

After nerve suture there is much crossing and mixing up of fibers so that it is not surprising that at first sensation is localized wrongly and muscle action may be uncertain in control By education and association the brain accommodates enough so that sensation and motion feel natural Even after brachial plexus repairs (Case J M, Fig 482) and transfer of nerves at the shoulder (Case E B., Fig 481) the feel of movements became natural. Sperry has shown, though, that there is a limit to how much the brain can adapt in such cases as crossed nerves of opposite function in animals (rats and dogs) have less power of adaptive learning than man

VOLUNTARY MOTION Motor function is more vulnerable to injury than is sensation, and on recovery of a nerve it appears later than does sensation.

Signs of recovery of sensation usually start after five months have elapsed from suture of the nerve. When sutured in the hand, signs of recovery may be seen in the first month. After sensation has reappeared over the whole limb to its tip, the quality of the sensation is at first far from normal, in that paresthesia is felt in response to the various stimuli This may persist in lessening degree for one to three years. By that time usually the quality of sensation approaches the normal

Voluntary motion may not appear until six or eight months after nerve repair, but when the first muscle is not far from the nerve juncture, as for instance after suture of the posterior interosseous nerve, I have seen it return as early as three months. Usually each muscle becomes innervated in a serial way, starting with the most proximal ones and ending with the distal Usually extensors or flexors of the wrist show movement first, then extensors or flexors of the fingers and finally extensors and flexors of the thumb The intrinsic muscles in the hand are usually last. An early sign is checking of the progress of muscle atrophy The earliest sign of motion occurs as a slight flicker to be seen or felt in the muscle belly or over the tendon. Actual movement first occurs only when the limb is held in such a way—namely, hanging or with the axis of the joint vertical—that gravity does not play a part. It may start as late as ten months after repair At first the movements are awkward, uncertain, and come slowly From crossed axones the wrong muscle may at first move, just as in return of sensation touch may at first be referred to the wrong area. Later misinterpretation from crossed axones disappears In beginning voluntary motion, the muscles move the limb through small amplitude and are very easily fatigued As recovery progresses, the amplitude and speed of reaction approach the normal, and finally force, endurance, and skill are gained.

ELECTRICAL REACTION This, as a sign of recovery, is uncertain. Usually, return of normal electrical reaction occurs only after voluntary motion has been reestablished. Galvanic reaction returns before faradic, and is first shown by an increase in speed of reaction, in contrast to the slow, vermicular motion of the reaction of degeneration. When this is seen it is a valuable sign of recovery It is doubtful if reaction to the faradic current ever precedes voluntary motion, and often—even when good voluntary motion is established—faradic reaction never reappears. It is only during recovery from partial nerve lesions that the reaction of degeneration leaves before the return of voluntary motion

A test for beginning motor return in doubtful cases (Van Wagenen) is made by inserting two tiny No 30 needles directly into the nerve one to two cm apart As a sinusoidal current connected to them is gradually increased, the muscle shows

rhythmic wave-like contractions and there is rhythmic pain at distribution.

Recently it has been found that the first signs of return of function of a nerve, even before clinical signs, can be shown by electromyography

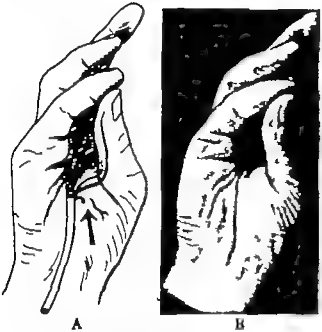


FIG. 290 Case S P Six months previously a laceration in the index finger resulted in tenosynovitis and an abscess in the thenar space. The latter was drained through an incision in the palm at the base of the thenar eminence. As the thenar branch of the median was severed the opponens pollicis and abductor pollicis muscles were paralyzed and had become atrophied, so the thumb could no longer oppose the fingers.

On August 4 this tiny nerve was sutured where shown in (A) with full recovery of the power of opposition 13 months later The photograph (B) shows that the thenar muscles are functioning well and that their atrophy has gone. (From Jour of Bone and Joint Surg., Jan., 1928)

TROPHIC RETURN After nerve severance, even if repair is done at once, trophic changes become progressively worse as the months go by. *When sensation is returning* the progress of trophic changes is at first checked, and by the time light touch is established over the whole area which was previously anesthetic, the trophic signs start to leave This is first noticed by return of function of the sweat glands and less satiny smoothness so that the skin, in running a finger over it, becomes more nonskid.

The severe atrophy of muscles from nerve severance may be prevented as shown by Jackson and Seddon if the muscles be given galvanic stimulation (90 contractions daily for six days a week) The treatment must commence early, as the greatest atrophy occurs in the first three months, and they must be kept up until the nerve recovers.

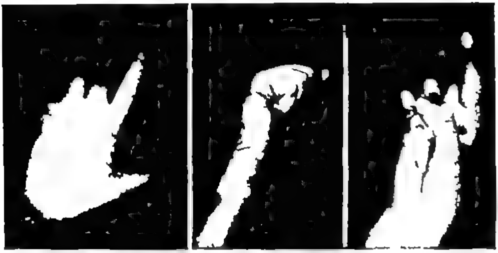
INDIVIDUAL NERVES OF ARM

MEDIAN NERVE

Anatomy The outer head of the median nerve arising from the anterior divisions of the fifth, sixth, and seventh cervical nerves carries the sensory fibers and activates the muscles of flexion of the wrist and of pronation, while the inner head arises from the anterior divisions of the eighth cervical and first thoracic and innervates the flexors of the digits and the muscles in the radial half of the thenar eminence. In its descent down the arm it leaves the blood vessels as it passes between the small ulnar and the larger humeral head of the pronator teres muscle and travels down the median part of the forearm between the sublimis and profundus muscles, riding on the profundus tendon to the index finger, until above the wrist it is radial to the sublimis and directly under the palmaris longus tendon Beneath the lower border of the *transverse carpal ligament, where it gives* off the motor thenar branch, it inclines volarward, branching to the first four digits in a plane superficial to the tendons and deep to the superficial vessels, though its branches in the fingers are volar to them. Just above the elbow its first muscular branches go to the humeral head of the pronator teres. From in front of the elbow to just below the pronator teres there arise, more or less in order, the branches to the remainder of the pronator teres, the flexor

carpi radialis, palmaris longus, and flexor digitorum sublimis. The anterior interosseous nerve branches from it at the upper border of the pronator teres Passing through the two heads, after giving branches to the deep forearm flexors, the flexor of the thumb and the radial half of the flexor profundus, it travels down the interosseous membrane to supply the pronator quadratus The unimportant superficial sensory branch to the palm leaves the nerve above the wrist on the radial side.

The musculature in the palm and hand is supplied by the median and ulnar nerves. Normally, the division between these nerve supplies runs down just ulnarward of the center of the flexor profundus muscle and for the muscles in the palm runs between the two heads of the short flexor of the thumb The usual division of the sensory supply is a line down the ulnar third of the palm and down the center of the ring finger The first two lumbricales are usually supplied by the median, and all of the interossei by the ulnar This line of division, in a small minority of cases, may shift either way Either nerve may supply the profundus of the long or ring fingers In the thenar eminence, the median nerve may even extend to supply the adductors and the first two interosseus muscles, or the ulnar supply may include the opponens pollicis. The division of the nerve supply of the lumbricales may shift one or two muscles either way Of the sensory area, the median may supply all of the ring or the ulnar all of the long finger, along their volar surfaces When either nerve supplies more than the normal it will be found to be relatively much larger



A B C

FIG. 291 Case H. L. A girl of 14 years thrust her right hand through a window severing just above the wrist both the ulnar and median nerves the tendons of the flexor ulnaris and palmaris longus also all of the flexor tendons, sublimus and profundus, of all fingers.
Operation Twenty four hours later the wound surface was excised and a primary repair was done on all of the severed tendons and nerves. (A) and (B) taken a year later show the power of flexion and extension obtained. Each finger can be flexed independently Sensation commenced to return in the hand in two months and at the end of a year complete sensation returned including stereognosis. She could spread the fingers except at the third cleft, as shown in (A) The action of the thenar muscles returned well, restoring opposition to the thumb as shown in (C) (Courtesy Surg., Gynec., and Obstet., 39 70 Sept., 1924)

A strange case was seen in which the extensor indicis proprius was supplied by the median nerve probably through the interosseus branch. The radial nerve was known to be severed and when the median nerve was blocked above the elbow the

proximal joint of the index finger could no longer be extended. In others, an old atavistic communication between median and ulnar nerves just below the elbow has been shown to carry the overlapping fibers.

Occasionally the nerve has been constricted between the lower end of the carpal ligament and the radius, causing pain and atrophy, after malunited Colles' fracture, fractures of the scaphoid, dislocation of the semilunar, and in arthritis Surgical relief of pressure stops the pain but the atrophy may not entirely disappear In some the nerve shows a thickening called pseudoneuroma of attrition It is thick from irritated connective tissue about the nerve, which may be peeled off allowing the nerve to expand to normal. In a personal case an aberrant artery closely accompanied the nerve in the tunnel, beating against it. Relief was obtained by excising the artery and cutting across the transverse carpal ligament at its radial attachment. In another was found an abnormally low muscle belly of the sublimis of the long finger contracting against the nerve.

Symptoms When Damaged. The radial nerve may overlap around the radial side of the thumb and thenar eminence or the radial border of the palm. The area of isolated median supply includes only the distal and part of the middle segments of the index and long fingers, both volar and dorsal. I have seen, however, in complete severance of the median nerve absence of any area of anesthesia. In an instance of severance of the median nerve, in which most of the thenar eminence and the interosseus muscles and even a portion of the hypothenar muscles were paralyzed, at operation the ulnar nerve was found to be unusually thin but intact.

In severance of the median nerve at the elbow above its branches, there is loss of *flexion of the thumb and the first two fingers* Flexion of the wrist is weak and ulnarward from the flexor carpi ulnaris. Pronation is weak. The upper part of the forearm shows, in place of its central and radial convexity, the hollowing of muscular atrophy, and the thenar eminence in its outer half is also conspicuously hollow The index and long fingers may show some flexion in their proximal joints, but are extended in their distal two, and the thumb is in a position at the side of the hand and cannot come forward from the hand in opposition. With the palm on the table, the index finger cannot scratch the table. With the two hands clasped the index and long fingers stand out without flexing

In a fair number of median palsies opposition of the thumb is not entirely lost, due to extension of ulnar nerve supply Even so, it is rare to be able to place the thumb as far forward from the base of the long finger as in the other hand and with the nail as parallel to the palm Often burns are seen in the pulps of some of the first three digits (Fig 281) Sensory loss is as shown in Figure 280, because of it and the high development of tactile sense in this area supplied by the median nerve, the main nerve of feeling, the manual worker is greatly handicapped. The injured median nerve is more frequently painful than are the other nerves in the arm, not only during recovery but often from minor injuries It is the usual nerve of causalgia. It may be compressed by swelling under the transverse carpal ligament or pressed by the flexor tendons against the carpal ligament in strong gripping when the wrist is flexed, or by an anteriorly dislocated lunate bone. This nerve is most frequently severed just above the wrist or in the palm and digits, but is also often injured in the upper arm and in the brachial plexus.

Surgical Repair Frequently, gaps in the nerve must be overcome. In the palm three-fourths of an inch can be gained by flexing the proximal finger joint. If more slack is needed the nerve can be freed to above the wrist and the wrist flexed. To overcome a gap in the nerve at or near the wrist, two inches can be gained by flexion

of the wrist. It is better, however, to gain some length by using the elbow also This can be accomplished simply by gripping the nerve with a piece of gauze and drawing upon it gently while the elbow is flexed This must be done with a sympathetic surgical feel to avoid overpulling The surroundings of the nerve will be found to yield almost two inches without breaking any of the muscular branches in the upper part of the forearm. By flexing the wrist and elbow, a 3½ inch gap in the nerve can be overcome A wide gap in the palm is overcome by freeing the nerve as far upwards as necessary, and, after flexing the wrist and elbow, drawing the nerve down. If the motor thenar branch is intact, it may be teased upward from the main nerve until it will not be pulled upon (Fig 305) If the gap is greater than 3½ inches, more radical means can be used, such as dissecting out the nerve in the upper arm, rerouting it superficially at the elbow, and flexing the elbow For this, it is necessary to strip up the various muscular nerve branches by the back of a pointed scalpel to well above the elbow, and by temporarily detaching the origin of the humeral head of the pronator teres to plant the nerve anterior to that muscle. If still more length is needed, the nerve can be exposed and freed high in the upper arm and the shoulder can then be flexed Plaster of Paris maintains flexion in these three joints for a month before gradual extension over the period of another month is allowed

By the above radical means a five-inch gap can be overcome. If a nerve graft is resorted to one should use the sural nerve in a three-strand cable graft. When the nerve is irreparable, muscle transfers are in order

The function of opposition of the thumb returned in two-thirds of 108 cases of median nerve suture above the wrist that I tabulated. If this function does not return in a year and a half or two years, a pulley operation of tendon transfer will furnish the desired opposition (See Chapter 10) This transfer operation may be done simultaneously with the nerve suture, as a gamble, to give early use of the thumb in high sutures of the median nerve and when the nerve has been long severed.

Radial Nerve

Anatomy The radial and axillary nerves spring from the posterior cord which is formed from the posterior divisions of the three trunks from the spinal nerves, and supply the extensor muscles of arm and hand The posterior division of the plexus also supinates the whole arm from the shoulder down, the radial nerve assuming this function from the elbow distally The radial nerve furnishes all of the extension to the elbow, wrist, and digits, with the exception of the distal two joints of the fingers which are also extended by the intrinsic muscles in the hand The *axillary nerve, which is from the fifth and* sixth cervical nerves, rides, along with the radial nerve, on the subscapular muscle to as far as its outer border It then turns backward and rounds the neck of the humerus to the deltoid, teres minor, and a patch of sensory area back of the deltoid This nerve may be reached either from in front or from back of the latissimus. In the latter instance, the arm is raised upright and the approach is through the hollow of the axilla. This is also a good approach for the radial nerve from the subscapulars to the upper part of the arm

The radial nerve proper then travels along the anterior surface of the tendons of the teres major and latissimus dorsi, to follow down the humerus, hugging it closely as it curves around it in the musculospiral groove, exactly along the line of maximal convexity of the outer head of the triceps.

Passing forward through the intermuscular septum, the nerve, following along under the brachioradialis muscle, divides at the elbow into its sensory and motor

branches, the superficial radial and the posterior interosseous nerves. The superficial radial continues under the brachioradialis muscle until it perforates the insertion of this muscle, to the subcutaneous layer over the dorsum of the radius and fans out in numerous branches down the dorsum of the first three digits The posterior interosseous nerve then dives through the substance of the supinator brevis muscle, supplying it, to emerge in the dorsum of the forearm between the superficial and deep muscle layers, dividing at once into two portions, one of these enters the under surface of the extensor digitorum communis, extensor digiti quinti proprius, and extensor carpi ulnaris, and the other runs on down the forearm to enter the superficial surfaces of the three extensors of the thumb and the extensor indicis proprius.

By systematically thinking where each branch, sensory and motor, leaves the radial nerve including the plexus, the level of the lesion can be accurately determined. At the lower border of the tendon of the latissimus dorsi, branches are in turn given off to as far as the inner, long and outer heads of the triceps muscle in the musculospiral groove, there being an additional branch to the anconeus and lower part of the middle head of the triceps between the two latter The posterior cutaneous branch comes halfway down the arm, dividing in two, one to supply a strip in the back of the upper arm and one down the dorsum of the forearm, until it reaches the area supplied by the superficial radial. When the nerve is between the brachioradialis and brachialis anticus, with branches it supplies both, and also the extensors of the wrist. The brachialis anticus has a dual supply because that muscle resulted from the fusion of the anterior and posterior primary muscle divisions.

Injuries In the arm the radial nerve is injured more often than any other, and due to its close proximity to the shaft of the humerus it often shares in fracture or becomes caught in the callus. By dislocations of the shoulder, it and the axillary nerve may be injured, and in the axilla it is affected in crutch and drunkard's palsy, the latter in hanging the arm over the back of a chair If traction for a fractured humerus is applied over the radial surface of the forearm, the posterior interosseous nerve usually becomes paralyzed. This nerve may be injured surgically as it rounds the neck of the radius, and it and the lower part of the superficial radial may be severed in lacerations.

Symptoms When Damaged. After high severance the resulting area of anesthesia is of not much practical importance, being a strip down the back of the lower half of the upper arm the forearm, and a triangular area on the back of the hand, bounded by the first two metacarpals and extending down the back of the thumb, the proximal segment of the index and half that of the long finger The area in the hand is quite variable in both size and shape and is not especially useful for tactile purpose. The isolated area, if any at all, may be only a small spot over the first interosseus muscle.

The radial nerve is rarely the seat of *painful lesions*, as is the median, though an injury to or a terminal neuroma in the superficial radial or its branches is often exquisitely painful, troublesome and difficult to remedy Any touch of the region, even to the coat sleeve, causes stinging pain, and necessitates either surgical treatment of the neuroma by severance of the nerve higher or suture of the nerve at the site.

The condition in radial paralysis known as wristdrop is characterized by pronation and drooping of wrist, thumb, and fingers. The thumb tends to be adducted, so it may *interfere with flexion of* the fingers. Flexion of the fingers is limited in this position, due to *relaxation of the flexors* and traction on the extensors, but if the patient throws

his arm in supination, the wrist falls into dorsiflexion and he can make a fist.

In testing the triceps, gravity should be eliminated by placing the upper arm horizontal, with the forearm hanging vertically In this position one can also test supination and extension of the wrist Action of the extensors of the wrist can also be determined by palpation over their muscle bellies and their tendinous insertions, and by placing the styloid process of the radius at the top so as to eliminate gravity when testing for ability to dorsiflex the wrist Finger extension is here judged only in their proximal joints. For thumb and finger extension, the tendons and muscles are watched and palpated. In the thumb, voluntary action of all three of the extensors should be sought for, that of the longus being easiest to determine as it affects all thumb joints. In loss of abductor pollicis longus the thenar eminence rides forward and the thumb is useless from loss of stability in its basal joint.

In testing for motions in the hand one should be constantly alert to guard against misinterpretation from seeing automatic movements. All other movements should be eliminated when testing for any particular movement, for if the patient is allowed to move either digits or wrist, or even pronate or supinate his forearm, he will be able to extend his wrist or fingers by these automatic movements.

In radial palsy, lateral movements of the wrist are very poor from loss of the long extensor and the extensor carpi ulnaris They are also accompanied by flexor movements, the motion ulnarward being accompanied by flexor movement by the flexor ulnaris. The grip is weak from inability to stabilize the wrist in dorsiflexion The styloradial reflex, which is entirely through the radial nerve, is absent. The hollow of atrophy on the dorsum of the forearm is conspicuous, whereas instead there should be the prominent bellies of the extensors of the wrist and extensors of the fingers

Surgical Repair The results of repair of the radial nerve are superior to those of the median or ulnar, probably because the nerve is more nearly pure, having only a minority of sensory bundles The superficial radial and posterior interosseus are pure nerves. To expose the radial nerve throughout its length in the upper arm requires three separate incisions, corresponding to the nerve's locations about the humerus In exposing it in front of the elbow, due consideration must be given the flexion crease by using a transverse or L-shaped incision to avoid keloid flexion contracture. The nerve is easily injured as it rounds the neck of the radius a finger's breadth below the head. To expose it in the supinator brevis this muscle must either be split in places or severed and rejoined. The approach in the forearm is in the condyle tubercle line between the extensors of the wrist and those of the fingers.

Gaps of three inches between the end of the nerve where usually injured at the humerus can be overcome by freeing the nerve downward and upward and strongly flexing the elbow For greater gaps the nerve can be transferred to an anterior position in the arm, passing it between the biceps and brachialis anticus to rejoin it at the inner side of the arm. Not much is gained by this Also the arm can be flexed at the shoulder across the chest. To accomplish this the various branches to the triceps muscle must first be slit by the back of a pointed scalpel far enough up the nerve so they will not be pulled upon Through a high incision the nerve should be freed in the axilla enough to be pulled down when the shoulder is flexed By these maneuvers even a five-inch gap in the radial nerve can be overcome

If the nerve be irreparable, or too long an interval has elapsed since the accident as shown by loss of reaction of degeneration muscle transfers should be made in the forearm These give such a passable result that this operation is preferable to

resorting to shortening the humerus to approximate the nerve ends. In cases where all extensor muscles were destroyed and adherent to the back of the forearm, there was such good function that no operation was advised. The fingers extended by flexing the wrist, and the wrist extended by flexing the thumb Frequently, following repair of this nerve, the function that returns is practically the normal degree

ULNAR NERVE

Anatomy The ulnar nerve arises from the inner cord which, in turn, is from the

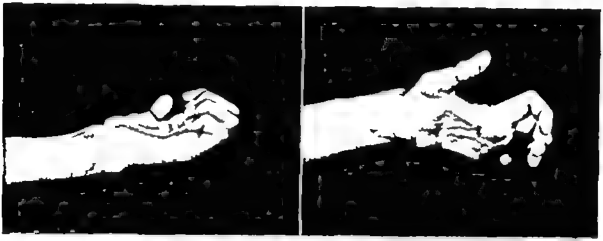


FIG. 292 (A and B) Extreme deformity from paralysis of median and ulnar nerves intensified by adhesions above wrist.

eighth cervical and first thoracic nerves. These, in contrast to the higher three nerves of the plexus which are for the arm, supply the hand as primordially when it developed from the fin of the fish. In its course down the arm at the inner side of the artery, in the lower third it leaves this vessel and passes around to the rear of the intermuscular septum, along the inner head of the triceps, to pass through the angle formed by the epicondyle and olecranon under the dense fascia which bridges across these two Here the first branches leave the nerve, and as the nerve dives between the humeral and ulnar heads of the flexor ulnaris muscle it gives a branch to each of these and two branches to the ulnar part of the flexor digitorum profundus. Coursing between these two muscles it is joined in the upper part of the forearm by the ulnar artery on its outer side, and the two then pass on together, the nerve giving a lower branch to the flexor carpi ulnaris muscle.

At the wrist the ulnar nerve—apparently to accommodate its more superficial sensory branch—detours with the artery forward

the fingers. There is no satisfactory transfer for paralysis of the triceps, and here gravity compensates somewhat for the disability

Splinting the limb so the paralyzed muscles remain in continuous relaxation is especially necessary in radial palsy, and until this is done, even after regeneration of the nerve, voluntary use of the muscles will not return. The airplane splint is used for the deltoid. A splint is not necessary for the triceps, as gravity keeps it in relaxation. Splinting is necessary to keep the wrist in mild dorsiflexion the proximal finger joints straight and the base of the thumb in moderate extension. All other joints and movements should be free. The Oppenheimer (Chap 4 Fig 96L) and the Thomas (Chap 4 Fig 96M) are satisfactory splints.

The return of muscle function after nerve repair usually occurs serially down the nerve as the respective branches come off, returning in most cases in the order of extensors of wrist, fingers, and thumb Usually all muscle groups regain function, but if one happens to be left out it is apt to be

through an opening in the transverse carpal ligament, only to leave the sensory branch at the lower border of this ligament and dive deeply between the abductor and flexor muscles of the little finger, again to become deep and travel across the palm with and branches supply the ulnar part of the palm and the volar surface of only the little and half of the ring finger These volar branches do not supply the dorsum of the last two finger segments, as in the case of the median nerve

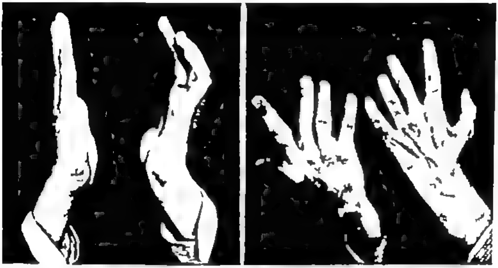


FIG. 293 Deformity and atrophy of intrinsic muscles from severance of ulnar nerve. The thumb can extend, flex, and oppose, but not adduct close to the palm. The clawing is mostly on ulnar side of hand.

beneath the deep transverse arch. While in front of the transverse carpal ligament it supplies the palmaris brevis and grooves the radial side of the pisiform bone there, separating from the sensory branch, it supplies the hypothenar muscles, and as it dips into the palm it loops around the ulnar aspect of the hook of the hamate In crossing the depth of the palm it supplies the inner two lumbricales in front of it and the interossei behind it, passing between the interossei and adductors of the thumb, both of which it supplies

The ulnar nerve in its course down the forearm sends a second branch to the lower part of the flexor ulnaris muscle and then a dorsal sensory branch leaves it, passing under the tendon of the flexor ulnaris to the side of the head of the ulna and over the tendon of the extensor ulnaris to supply the dorsum of the ulnar part of the hand the dorsum of the little and ring fingers to the root of the nails and the ulnar half of the dorsum of the proximal segment of the long finger The two volar sensory

Injuries. From lacerations the ulnar nerve is frequently severed just above the wrist or there may be severance of the volar digital branches in the palm or fingers or by penetrating wounds, the deep motor branch About the elbow the main nerve is frequently injured from fracture, dislocation, or direct blow, or may later become involved in the callus. Occasionally the nerve is involved in lacerations in the upper arm. Here it is vulnerable to pressure from the edge of an operating table if the arm is not kept at the side. Only occasionally is the nerve injured from hanging over the back of a chair in sleep, but it is the one most frequently affected by pressure between the scalenus anticus muscle and the bony prominence beneath (though the thenar muscles supplied by the median nerve and some flexors of the fingers may also be involved in this)

Symptoms When Damaged. SENSORY The ulnar border of the hand and the little and ring fingers, both on the palmar and dorsal surfaces constitute the area of anes-

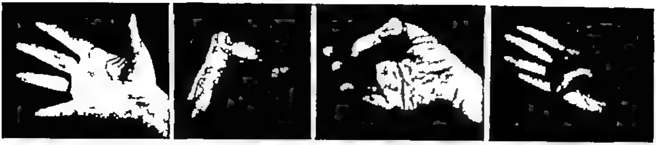


FIG. 294 Restoration of complete function after suture of ulnar nerve at wrist, seven months previously severed on a window

Photographs taken two years after nerve was sutured show four tests for ulnar-nerve function Reading from left to right

The spread of fingers.

Flexing proximal joints and at same time extending distal two joints.

Ability to pinch firmly making a good O and arch of thumb without the metacarpophalangeal joint dropping into extension (adductor test)

Ability to scrape the extended thumb across the fingers and palm (adductor test)

thesia to light touch and pinprick commonly resulting from severance of the ulnar nerve Occasionally the anesthesia may run a few inches up the inner side of the arm due to a low sensory branch of the nerve, but if it runs higher along the ulnar border of the forearm, showing involvement of the internal cutaneous nerve a higher lesion must be suspected The isolated sensory supply is limited to the little finger From overlap there is usually some improvement in a few months, shown by shrinkage of the above-mentioned area of anesthesia. Trophic changes are seen in the skin of the anesthetic areas and often burns in the pulp of the little or ring fingers.

MOTOR In severance of the ulnar nerve above the elbow there is paralysis of the flexor carpi ulnaris and the ulnar third of the flexor profundus muscles resulting in a conspicuous hollow over these muscles from atrophy and of loss of ulnar flexion of the wrist and of flexion of the distal joint of the little finger so that when the hand is palm down the little finger cannot scratch the table. Also all of the hypothenar and interosseus muscles and two lumbricalis muscles on the ulnar side, the adductors of the thumb and the inner head of the flexor pollicis brevis are paralyzed. This results in atrophy of these muscles of the hand shown by conspicuous concavities over the first interosseus muscle, the hypothenar eminence, and between the metacarpals.

There is also deformity of the hand in that there is some clawing of the ring and little fingers. This clawing, however, is less conspicuous when the ulnar nerve is severed above the elbow It is greater when severance occurs below the nerve supply of the ulnar part of the flexor digitorum profundus muscle. This muscle then, unopposed by the intrinsic muscles in the hand, draws the distal two joints of the ring and little fingers into flexion while the proximal joints become extended If the profundus is strong clawing is great but the flexion is greatest if the flexor tendons are adherent in the forearm The clawing may involve to some extent, the long finger, but is most prominent in the little the two radial lumbricales which are supplied by the median nerve sparing the deformity in the index and long fingers. The ring and little fingers can no longer simultaneously flex their proximal joints and extend their distal two In high ulnar palsy the little and ring fingers do not flex well in making a fist.

In ulnar paralysis lateral motion of the fingers is largely lost. The index and long fingers deviate ulnarward but some may still radioflex weakly from their lumbricales and because fingers diverge on extension the long extensors may spread the fingers moderately, especially the little finger The first interosseus muscle is conspicuously

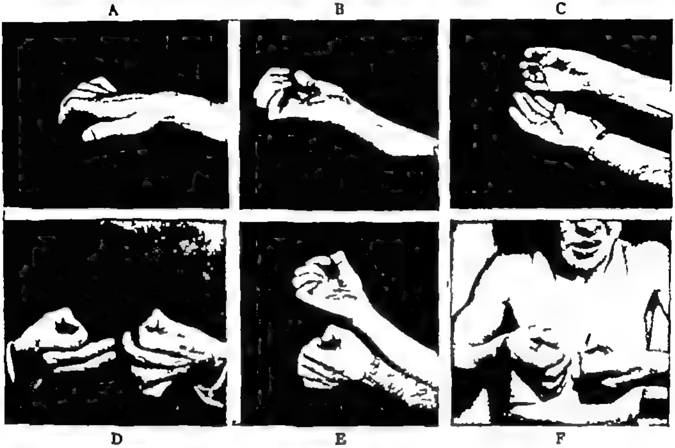


Fig. 295 Signs of paralysis of ulnar nerve.
Case R. C. Ulnar nerve severed above wrist.
(A and B) Atrophy of intrinsic muscles supplied by ulnar nerve. Hypothenar and first inter osseous concavities are conspicuous. Clawhand is greatest toward the ulnar side and more pronounced when the nerve is severed below its supply to the flexor digitorum profundus as in this case.
(C) Scrape test. With loss of the adductors of the thumb the extended thumb cannot scrape across the extended fingers and palm, but leaves the palm at the radial side of the index finger as in the upper hand.
(D E, and F) Pinch test to show loss of action of short adductors of thumb
The normal thumb makes a good O with the index finger and pinches firmly with a good arch to the thumb (left)
In ulnar paralysis the O is faulty the distal joint overflexes the metacarpophalangeal joint drops into extension and the pinch is weak. A paper can be easily pulled from between.
A similar deformity occurs when the tendon of the abductor pollicis longus is severed
For proper muscle balance in the pinch the adductors of the thumb should stabilize the proximal joint in flexion and the long abductor the carpometacarpal joint, in extension. (See Fig. 39)

atrophied and cannot be felt to activate in the feeble attempts to abduct the index finger By testing, however, each finger individually for lateral motion, including adduction of the little finger, the paralysis will be apparent. In this, it helps to place the hand palm down on a flat surface or to flatten the metacarpal arch, or to test lateral motion when the proximal joints are in slight flexion. With the fingers partially extended it is impossible to converge their tips.

The thumb in ulnar paralysis due to loss of the adductors, no longer pinches against the index finger to make a good O or against the little to make an ellipse The pinch is weak the metacarpophalangeal joint may drop into hyperextension and the distal joint of the thumb into excessive flexion In other words, the arch of the thumb is lost because there is loss of ability to stabilize the metacarpophalangeal joint in flexion The pinch of the thumb will be very weak. A paper held between the thumb and index finger can easily be withdrawn It should be noted that loss of the stabiliz

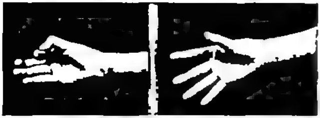


FIG. 296 Deformity of dropped metacarpophalangeal joint of the thumb in pinching against the index finger A good O cannot be formed as the arch of the thumb breaks down.

The phenomenon is seen after severance of the tendon of the abductor pollicis or of the ulnar nerve, but this case, as seen in the right hand picture, is due to a third reason, there being a cicatricial flexion contracture between the first two metacarpals or a backward dislocation of the thumb metacarpal on the trapezium.

ing action of the abductor pollicis longus in holding the carpometacarpal joint in extension will give the same deformity and weak pinch, and similarly cicatricial contracture between the first two metacarpals (Fig 296) To pinch firmly against each other, the index finger should abduct and the thumb adduct. This action of both the first interosseus muscle and the adductor of the thumb is lost in ulnar palsy (Chap 10, Fig 420)

In ulnar paralysis, the extended thumb can no longer scrape across the bases of the fingers and distal part of the palm. Instead, it leaves the palm and comes forward at the radial border of the index finger As the adductors are recovering it may leave the palm at various points farther ulnarward. Atrophy and loss of voluntary motion of the adductor muscles of the thumb can be felt by through-and through pinching of these muscles when the thumb attempts to adduct against resistance Normally, the thumb adducts—though somewhat dorsally—also through the action of the extensor pollicis longus muscle. In ulnar paralysis the muscle balance in the hand will be so upset from loss of action of the intrinsic muscles that the hand will have lost its skill and be quite awkward at work.

Many of the tests for ulnar nerve paralysis which have just been mentioned may not be completely conclusive because of variability in the division of nerve supply between the median and ulnar nerves, both in their sensory and motor distribution, as has already been described for the median nerve. The pinch test of the thumb and the ability to oppose the thumb are, for this reason, especially variable. Lesions of the cord or lower two nerves of the brachial plexus need not be confused with ulnar nerve palsy if the nerve examination is sufficiently extensive, for in poliomyelitis there will be absence of sensory symptoms, in syringomyelia a dissociation of temperature and pain from touch, and in other cord lesions signs of involvement of the long sensory or motor tracts. When the lower two nerves of the brachial plexus are involved, paralysis of the muscles of flexion of the fingers and of opposition of the thumb, combined with anesthesia of the internal cutaneous nerve, should warn us from error

Surgical Repair The results from repair of the ulnar nerve are usually not quite so good as in the case of the median and especially as in the case of the radial, evidently because the number of sensory and motor axones are more equally distributed, thus accounting for the loss of either when growing down wrong pathways. Much, therefore, depends on the exact rotation when suturing such a nerve, as almost perfect recoveries are seen, as illustrated in Fig 294 The median low in the forearm is almost purely sensory and the radial low in the upper arm is almost purely motor, which accounts for good results from suturing these, even with inaccuracy in rotation. Suture of either the motor or the sensory branches of the ulnar nerve in the hand gives excellent results.

In the ulnar nerve above the wrist a gap of almost two inches between the ends can be overcome by flexing the wrist. For longer defects one must transplant the

nerve from the back to the front of the el bow and then flex both elbow and wrist, thus overcoming a five inch gap More can be gained by freeing the nerve high and flexing the shoulder To transplant the nerve at the elbow a midlateral incision is made paralleling the nerve, and the large triangular flap of skin is dissected forward from the deep fascia The length of the nerve is uncovered by slitting the fascial bridge at the condyle and on down through the flexor ulnaris muscle between its two heads. The nerve can then be lifted out of its groove, and is held only by its motor branches These are slit up with the back of a pointed knife to well above the elbow, so they may remain in place without hold ing back the nerve when it is transplanted forward

In women, or in persons with weak mus-

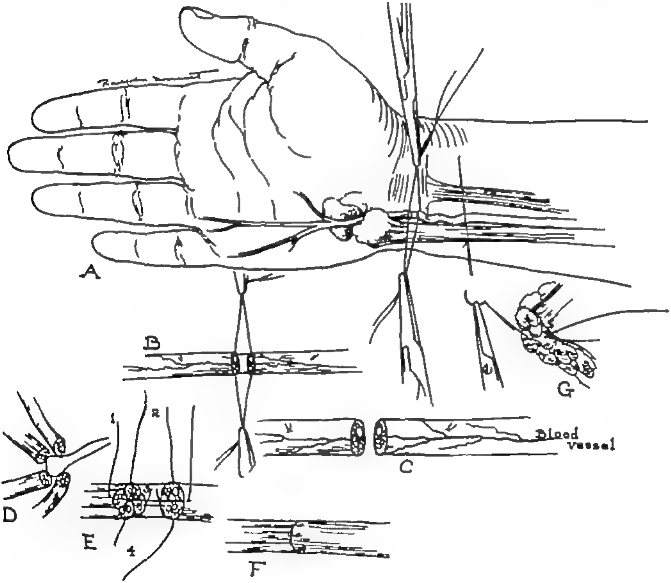


FIG. 297 Method of suturing a nerve (ulnar)

(A) During suturing the proximal end may be held free from tension by impaling it on a needle. The ulnar nerve is anterior to the carpal tunnel lying on the transverse carpal ligament. Its relationship to the pisiform and hook of the hamate and its motor branch are shown.

(B and C) Exact rotation is determined by marking the midline of each nerve by a knot of silk, by the flatness of the nerve, by matching the nerve bundles by the striations of the nerve, and by the blood vessels Two guide sutures are then placed.

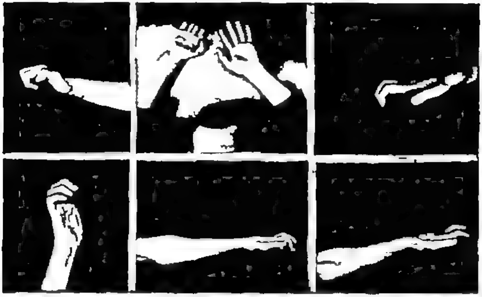
(D E and F) Method of suturing a main nerve to its several branches or suturing a cable graft. First one stitch groups the branches into one and then the suturing proceeds as usual.

(G) Greasing the thread before using.

cles, the nerve may be left between the deep and superficial fascia, suturing these two together to keep the nerve from displacing backward *but in muscular individuals it* will be found that the prominence of the flexor muscles is so hard that the nerve will be subject to injury from pressure upon it by outside objects. It has been recommended to place the nerve in the deep fascia and muscles, but here there will also be pressure between these two on muscle contraction. *It is better to reroute the nerve* between the flexor profundus behind and the flexor sublimis and pronator teres in front. This can be done by disconnecting the origins on the epicondyle of the latter two and reconnecting them again, or in case the nerve is parted in the vicinity the intermuscular passageway can be tunneled and the nerve end drawn through.

In ulnar nerve recovery the forearm muscles, and then lower down the nerve sensation, are first to recover Hypothenar muscles follow and finally the interossei and the adductors of the thumb Muscles within the hand rarely show much return under a year Voluntary action is first noticed in the hypothenar muscles. Later the clawing lessens, and finally come lateral motion of the fingers and adduction of the thumb Occasionally in the recovery one or several of these intrinsic muscles is left out. Early signs of recovery are pain on pinching the hypothenar muscles and a hypothenar reflex on pressing the nerve just proximal to the pisiform. Sensation *usually returns throughout the whole anesthetic* area, though good quality of sensation returns last in the little finger Stereognosis returns after a year and a half, though even normally it is not so keen in the ulnar as in the median area.

A B C



D E F

FIG. 298. Deformity and atrophy from severance of both ulnar and *median nerves, flat hand, thumb at side, all fingers clawed, and all intrinsic* muscles atrophied.

(A and B) Marked clawing as flexor muscles in forearm are preserved.

(C and D) Marked clawing as severed flexor tendons are attached firmly in forearm.

(E and F) Moderate clawing only as nerves are severed above the flexor muscles in forearm which, therefore, show atrophy

Splinting in ulnar palsy is not necessary unless the clawing is pronounced as it is when the profundus action is strong, it should consist of holding the proximal joints of the ring and little fingers in flexion. A *simple contrivance for this is two light rubber* bands stretching from in front of the wrist from a wristband to two soft leather

loops over the dorsum of the proximal segment of the ring and little fingers If stronger action of the fixed deformity is needed at the beginning, a splint of sheet aluminum, held to the dorsum of the hand with a web belt, and an extension to hold the proximal joints of the ring and little fingers in flexion, will suffice. Clawing is greatest when the flexor muscles are adherent in the forearm. Tendon transfers for ulnar palsy, i.e., to abduct the index finger and restore muscle balance to the last two fingers may be found in Chapter 10 Transferring the extensor indicis proprius to act as an abductor may be done in a late case at the time of the nerve suture. When the little finger is permanently clawed and anesthetic it should be amputated, and especially if the patient works with machinery

Combined Nerve Lesions

In these the area of anesthesia is greater than one would expect because the overlap is equivalent to an isolated nerve supply The disability is crippling from paralysis of the two sets of muscles

Combined Lesions of Median and Ulnar Nerves This combination is commonly encountered in hand surgery from lesions in the forearm and upper arm, up to where the radial nerve leaves them. The area of anesthesia covers the whole palm and volar surface of all the digits and also on the dorsum the area of the dorsal surface of the ulnar nerve the last two segments of the long and index fingers and the last segment of the thumb From overlap of the radial and internal cutaneous nerves there may be a little feeling left in the palm at the cleft of the thumb and over the thenar eminence. Much of the anesthesia is to all for all sensation, and even the joints show stiffening

Deformity is conspicuous The wrist bends slightly backward and ulnarward unless there be flexion contracture there and the hand inclines toward supination Because of loss of the intrinsic muscles of the hand, the carpal and metacarpal arches

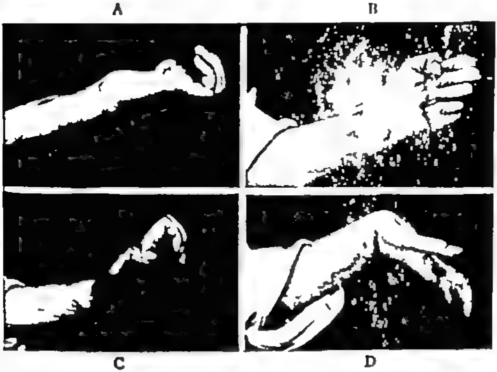


FIG. 299 (A and B) Deformity from severance of both median and ulnar nerves in laceration above the wrist namely flat hand, thumb at side, no opposition, and clawing of all fingers.
(C and D) Automatic movements by wrist of flexion and extension of digits because flexor tendons are adherent just above wrist.

FIG. 300. Typical deformity of combined median and ulnar paralysis loss of arches, thumb at side, all fingers clawed, atrophy of intrinsic muscles. Nerves are severed at elbow but flexors in forearm are spared.

At the extreme right is shown a corrective splint applied to the same hand. The knuckle bender is better

straighten, so that the hand is flat. The thumb is at the side of the hand, without power of opposition or adduction. The amount of clawing of the fingers and of flexion of the thumb depends on whether the lesion in the nerves is above or below the nerve supply of the muscles in the forearm If above, these deformities are not so great. If below, however, so the flexors in the forearm are activated, clawing of all fingers is extreme, there being hyperextension of the proximal joints and sharp flexion of the distal two—the long flexors being unopposed by the paralyzed intrinsic muscles Clawing is greatest when the flexor muscles are adherent in the forearm. If the lesion is above the nerve supply of the forearm muscles, the long flexor of the thumb, as well as the thenar muscles, will be paralyzed and the thumb will assume a position back of the plane of the hand, drawn there by its long extensors If the lesion is below the forearm muscles, the thumb will be able to flex, but it will be at a position at the side of the hand, devoid of opposition and adduction. In combined median and ulnar palsy, if the nerves are irreparable, muscle balance in the fingers, abduction of the index finger, adduction and opposition of the thumb may be given by tendon transfers as outlined in Chapter 10 In severe rigid clawing of long standing the middle finger joints may be arthrodesed in mild flexion and similarly the distal joint of the thumb if overflexed. A great variation in deformities of the hand from positions assumed occurs from combined lesions high up the arm and in the brachial plexus, depending upon which muscles are paralyzed or spared.

Splinting is necessary in combined median and ulnar nerve paralysis to hold the proximal finger joints in flexion, the arch curved and the thumb in opposition A neat ducoed encasement of plaster of Paris, or castex, covering dorsally the proximal finger segments and hand, and clasping the palm with a crossbar curved along the distal crease has been customary An extension from it should shove the metacarpal of the thumb into opposition. (Fig 300) The same may be made of aluminum with web strap and buckle. These are objectionable because they are rigid The best splint for this seems to be the knuckle bender (Chap 4, Figs 96A and 96B) The rubber bands can be very light, just strong enough to be persuasive to keep the proximal finger joints flexed and the thumb in opposition The splint is light, does not extend on the forearm and leaves the hand free for use in occupational therapy etc. There is an attachment to it which will extend the distal two finger joints. Rubber bands over a roller on an extension draw out the fingers.

TREATMENT OF INJURED NERVES

The Hand in Nerve Injury Considering that the hand is all important in the upper extremity and that it is wrecked by brachial plexus injury or the severance of one of several nerves in the arm, it is clear that the object of repairing that limb is to restore function to the hand.

If attention is directed to the nerves only, the hand will become fixed with the joints stiff and in deformed positions so that function will be impossible. Such a hand, if not exercised, will atrophy from disuse until it is but a useless claw If, in addition, there is arterial damage, the stiffening and mal nutrition are intensified

In nerve cases of the upper extremity active treatment should be given to the hand from the time of injury to the resumption of employment. It should consist of keeping the hand in the position of function, keeping the joints mobile and encouraging whatever movements are present. At first physiotherapy is necessary until use returns to the hand and then occupational therapy is in order The patient should be taught how to move the joints of his hand with his other hand and instructed to move them gently but continuously until function returns. This is the best physiotherapy It should be strictly carried out. Some will need arthrodeses and tendon transplants Precautions should be taken not to burn or injure the injured part The surgical repair of the nerve requires but a short time, but attention to the hand must be continuous. Cases with upper extremity nerve injury especially in organized hospitals, should be seen in consultation with a hand surgeon, and, also should eventually be cleared by him lest some advantage to the hand may be overlooked

Splint to Keep Paralyzed Muscles Relaxed After every injury we should routinely search for nerve involvement and if found the limb should be splinted so that the paralyzed muscles will be kept in relaxation for as many months as is necessary until they recover

When a muscle is paralyzed, its antagonist, now unopposed, draws the limb into deformity so the paralyzed muscle becomes too long When the nerve finally regenerates, the elongated muscle is at such a disadvantage trying to work against the resistance of the healthy muscle that recovery will be limited or greatly delayed until the muscle finally shortens Therefore, splinting is necessary to prevent overstretching The splint need not hold the limb over corrected to the opposite deformity, but merely hold it in the position of function Rigid over-correcting splints have been used that stiffen and even wreck hands, prejudicing some against splinting for nerve injuries The fault was in the type of splint The splint should be light, minimal in size and should not interfere with the continual use of the hand It should not be rigid, but elastic or springy, for full use of the hand so the hand will stay active and limber The strength of spring should just counterbalance for the loss of muscle power and not support any joints except those involved Ulnar palsy should be splinted only when the long flexors are strong enough to produce clawing Radial palsy, and that of combined median and ulnar palsy, require splinting as described under those nerves

When to Operate. Whenever possible, nerves should be repaired before tendons, because in a paralyzed limb no tissue thrives and tendons and joints become adherent How soon following an injury should we repair the nerves? Primary suture gives quicker and better results than secondary, but this should be done only when surgical conditions are the best, so as to make a perfect nerve juncture Immediate primary suture yields the quickest and best results In wounds from explosives the nerves may have been injured further back than appears Allowance could be made for that but because of the explosive character of the wound it is bet

ter to postpone the neurorrhaphy until a clean suture can be made. Should infection occur, there is no great damage done and the nerve can be resutured. Nerves are fairly resistant to infection and afterward can be resutured. The nerve should never be sutured in presence of infection or an open granulating wound, because the junction will not be 100 per cent perfect. Nerve repair should be postponed in the presence of an infected wound until at least four months have elapsed since the final healing. The time can be greatly shortened by penicillin. Osteomyelitis should be cleared early so that nerve suture will not be postponed too long. Then it is well to use penicillin and avoid trespassing on the bone or scar lest latent infection be liberated. Otherwise a delay of ten months would be necessary for safety.

It has been found in tabulating war wounds that half the cases with nerve injury recover spontaneously. This, of course, includes many minor cases and those in which the nerve was physiologically blocked because of the proximity of a passing missile. Of those nerves that were severed or that eventually required surgery, it would have been better to operate earlier. Sensation returns after nerve repair, even though done six years after the injury, but motor nerves should be repaired as early as possible, because the steadily progressing fibrous degeneration of the nerve and muscle will make it unfit for function if the nerve is repaired too late. Many good results are obtained by repairing the nerve a year after the accident. We should repair a motor nerve even up to two or three years though two is usually considered the maximum time. If the muscle still reacts to the galvanic current it will react to the repaired nerve. This is our best guide.

If the type of wound is such that the nerve is probably severed, operation is indicated. Most nerves show at least some signs of recovery in five months. Absence of any of these signs is an indication to explore. An exploratory operation, carefully done, with due consideration for the other structures in the limb, does no harm and in many cases will give the patient the opportunity to have his nerve repaired early. As regards motor function at least, the earlier the repair the sooner and better the recovery.

The proper functioning of the hand is so dependent on the arm nerves that, as soon as the wounds have healed, repair of the nerves of the arm should have priority, considering the hand as the important part of the arm. These should be repaired at the same time or even sooner than the skeleton. Paralyzed muscles undergo continuous fibrous degeneration until checked by nerve regeneration, so the nerves should be repaired as soon as possible before it is too late. This work should not be postponed for many months until the bones may first unite. Also, soon after an injury, joints may be flexed, thus allowing nerve ends to be approximated. It is impossible to approximate nerve ends if the adjoining joints have stiffened in extension. It is important for nerve suture to be able to flex well the elbow or knee. If the elbow is stiff, it may be necessary to bend the arm at the fracture or to separate a fused joint to accomplish it. The median and ulnar nerves are the most important for the preservation of the hand. The loss of the radial nerve can be compensated for somewhat by tendon transfer.

Primary vs. Secondary Suture. Following primary repair of any wound the surface scar in the skin is usually coarse and for cosmetic purposes is frequently later excised under clean surgical conditions and resutured. The same is true of the junction of the severed nerve repaired primarily. A repair that is done at the time the tissue was traumatized and potentially infected, even though primary healing occurred, will usually result in a very crude union of the nerve ends just as we see in

surface scars. Considering that the degree of recovery after nerve suture is in direct proportion to the accuracy and perfection of the juncture, the patients who are not reoperated on after the usual primary nerve repair are denied the chance of obtaining as good a result as that to which they are entitled Having uncovered in secondary operations a great many such cases, I am convinced that the usual finding after primary suture is that a very cicatricial, inaccurate juncture has taken place In these cases, by following our rule to resuture nerves primarily repaired, the findings have fully justified the procedure

For the usual primary treatment of severed nerves it is advisable merely to attach the two nerve ends together with one stitch of S.S wire to keep them from retracting, so that when later they are secondarily repaired they will be found to be in proximity

This, however, does not apply to fresh wounds treated in the best surgical surroundings, by complete excision of every particle of the wound and conforming to the surgical principles described in Chapter 12 This converts a traumatized, potentially infected wound into a clean surgical wound, and here primary suture is advisable and gives excellent results—even better than does secondary suture

Frequently, a patient who has had a primary suture a year previously has obtained a partial or mediocre recovery Shall we resuture the nerve, destroying the precious function he has already regained in hope of obtaining better function later, or not? When resuture is done routinely early after an injury, such a *predicament will not arise*, and in the long run the results will be far superior

Technic of Nerve Repair In dissecting a nerve out from scar we should not approach it within the scar, where we may damage the nerve, but should approach from above and from below, following the nerve into the scar It is preferable always

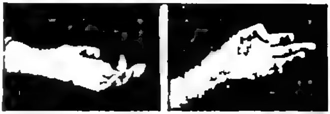


FIG 301 Case M T One and one half years previously palm and thenar eminence were shredded in a cotton gin destroying all branches of median and ulnar nerves including their motor ones.

Opposition was restored to thumb by the pulley operation using for motor the flexor ulnaris for pulley a slip from same and for tendon the extensor pollicis brevis

The motor branch of the ulnar nerve was joined by a 1½ inch graft from the sural nerve and also the branches to the long ring and little fingers to the ulnar nerve by 2½ inch grafts. The median nerve was drawn down and sutured to its sensory branches

(*Left*) Preoperative loss of opposition of thumb

(*Right*) Restoration of opposition (partial)

A check up after two years showed sensation to light touch and pinprick restored throughout except tips of long and ring fingers, and coarse touch throughout. Some signs of regeneration of the ulnar motor branch were moderate abduction of little finger ½ inch of lateral motion of index finger measured at tip, ability to flex proximal finger joints, and at same time to half extend the distal two

to dissect the nerve downward, for fear of tearing off its branches. It is imperative to have a dry field A tourniquet should be used wherever possible, and if the location does not permit a tourniquet we should stop and tie or fulgurate every tiny vessel to progress always in a dry field Cotton pledgets are almost universally recommended in nerve work for sponging I believe them bad, having frequently seen, in *later operation, much tissue reaction resulting* from them The cotton pledgets are not left in the wound, but wisps of cotton from them are, the tissues producing about them zeppelin shaped foreign body reaction even 8 mm in length Inside these were wisps of cotton

As soon as each nerve end is uncovered a single stitch of black silk should be placed

in its topmost part to mark the proper rotation, which is so all important for perfection of result. Other guides to rotation are the oblong shape of the cross-section of the nerve as it lies in its bed away from the site of trauma, and striations along it such as from funiculi or blood vessels, which can be matched in each nerve end On cross-section the pattern of the funiculi should be studied in each end and matched with each other as accurately as possible For instance, in a median nerve above the wrist is one special bundle destined for opposition of the thumb, and if not properly matched this function will not return. Usually, the funiculus for any particular nerve is found on the side of the main nerve from which that nerve arises Eventual recovery is proportionate to exactness of rotation and accuracy of coaptation of the nerve ends.

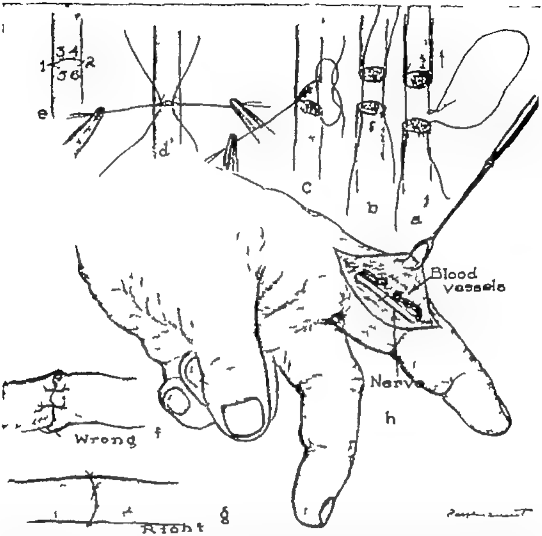


FIG. 302 Suture of volar digital nerve joining only the sheath and with the finest silk. Accurate approximation insures good regeneration. Nerves can be sutured to as far as the distal digital crease. The motor thenar branch of the median can readily be sutured.
(a to e) Order of procedure.
(f) Careless repair gives poor result.
(g) Accurate repair

The terminus of the upper segment of the nerve will, after three months, be found to be an enlargement or neuroma in contrast to the smaller, though slightly swollen, lower end which is a glioma. With sharp plastic scissors each nerve end is cut off boldly until a perfect pattern of funiculi

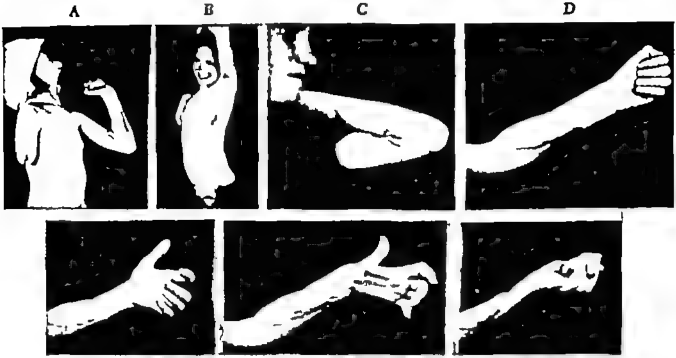


FIG. 303 Case H. T On September 4 1938 with the right hand she grasped a high voltage transformer and the left forearm touched a ground wire. Right arm was amputated. In the left arm flexor muscles, median, and ulnar nerves were destroyed.

(A) Condition when brought for repair All intrinsic muscles are paralyzed. No flexor to digits is functioning Anesthesia covers the hand and lower forearm with exception of area supplied by radial nerve.

(B) Vertical pedicles leave unsightly scars. This was later excised and zigzagged.

Operation June 12, 1939 It was imperative to repair the nerves, especially to restore the intrinsic muscles in the hand. Much scar was excised from forearm and elbow and keloid borders of pedicle. A four inch gap in the ulnar nerve and a three-inch one in the median were overcome by transplanting each and flexing the elbow The only remaining muscle tissue was dissected out with a long strip of scar tissue and connected up to the tendon of the thumb. Two plastic procedures were done later to eliminate the contractures and keloid borders of the pedicle.

By January 30 1940 eight months later sensation had returned throughout and by July 18 1942 three years from nerve suture all intrinsic muscles of the hand were working.

(C, D E, F and G) Show relief of contracture of elbow and of clawhand, return of automatic movements by flexing and dorsiflexing wrist, the flexors of the fingers acting as tenodeses

is seen, with the axone bundles projecting like the wires from the cross-section of a cable. To do this, we must usually cut through the soft neck of the neuroma. The nerve ends should be crisp and free from any intervening cicatrix and by delicate handling should be kept firm and unfrayed

In suturing either a tiny No 16 straight Kirby needle is used threaded with the finest silk such as that used in suturing blood vessels or as I prefer a Davis and Geck atraumatic eye suture with curved weld on needle and very fine black silk size 7-0 Six-0 is too coarse Using a straight mosquito hemostat as a *needle holder* the thread is first greased by being drawn through some nearby fat—vaseline is to be condemned as it causes a bad tissue reaction Tantalum wire No 40 has been used to lessen reaction, but accuracy in axone approximation and sheath closure seem to be the true essentials A single tantalum wire can be tied into the sheath on each side of the juncture in order that we may tell later by x ray, whether the nerve has pulled apart. Otherwise there is no advantage in the wire as a suture over the 7-0 silk as it is located in the sheath, and there is the disadvantage of me*chanical irritation by the stiff and pointed*

metal in movable tissue. For the latter reason, wire should never be used in small hand nerves, subject as they are to repeated trauma. First, two guide sutures are placed, using double strands for large nerves interrupted stitches are placed, using a total of six to four, but for nerves the size of the median a continuous stitch will better close the sheath so that no wild axones will escape If they do, they will cause Tinel s

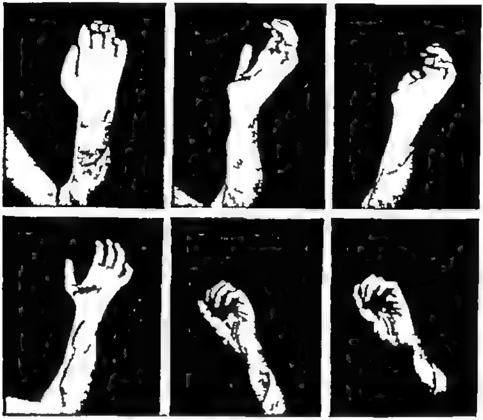


FIG. 304 Case N G Volar aspect of forearm was gouged out by an automobile wreck, including all of the muscles except at the extreme top of the forearm. A pedicle graft had been applied to the forearm.

(*Top*) Showing condition when coming for repair Flat hand, thumb at side, absence of opposition as shown at extreme right and limit of extension and flexion of fingers as shown in first two pictures.

Operation. A five inch gap in the median nerve and a four-inch one *in the ulnar nerve were overcome by freeing, transplanting, and flexing.* A strand of scar was used for a thumb flexor A pulley operation for the thumb was done, looping the tendon about the tendon of the flexor ulnaris. Distal parts of tendons were freed but left adherent in the forearm to act in moving the fingers by automatic movements.

(*Bottom*) Condition a year later showing motion of fingers, opposition of thumb and curve of hand. Sensation had returned throughout and motion in intrinsic muscles was just starting.

and single ones for small. A mosquito hemostat is placed one-half inch away on each guide. The guides must be exactly placed as they determine the rotation All nerve sutures should catch the nerve sheath only Between the guide sutures one can approximate the sheath edges by either the interrupted or continuous stitch. In small nerves such as those in the palm or fingers sign and be lost. After suturing one side a guide suture is passed under the nerve and the nerve is turned around for suture of the other side. Extreme accuracy is needed for a good result.

In repairing the tiny nerves in the hand, a hand lens is useful in determining that we have good axone bundles. No nerve that can be sutured, even though we use only

two stitches, is too small to regenerate. This has frequently been proved in cases occurring in the hand—the motor branch of the ulnar, the motor thenar branch of the median nerve, and in the face—one inch in front of the ear, the tiny branches of the facial nerve

If the nerve ends in the hand do not reach, the main nerve, median or ulna, is dissected up into the forearm or further and the wrist, or wrist and elbow, are flexed. To avoid pulling on the motor branch when the nerve displaces downwards, the motor branch should be stripped up from the nerve far enough to avoid tension. In this way large gaps in motor or sensory branches may be overcome.

In suturing nerves in the wrist, elbow, or bases of the fingers, when these joints must be flexed in order to allow the nerve ends to come together the task is often quite awkward and one must work off balance and sometimes upside down, however, it can be done. After suturing the nerve the juncture is rolled a little between the finger and the handle of a scalpel so as to arrange the bundles properly, and then is placed in a good bed of normal tissue. For this, first the surrounding cicatrix is dissected out. A space between two muscles or in good, soft fat is excellent for a bed. Occasionally, one must swing a pedicle of fat from a nearby location or lay over a piece of smooth fascia to separate a nerve juncture from scar tissue. If the juncture be placed in scar, that scar will generate more scar, which will encase the nerve and jeopardize the result. Certain policies in nerve suture should be mentioned only to condemn them, such as intubation of the nerve juncture with various membranes blood vessels, or even foreign bodies. They only create more cicatrix, and if any regeneration occurs it is in spite of them

To envelop a nerve juncture in a sheath of tantalum foil is to effectively build about it a fence that prevents the ingrowth of blood supply so necessary for healing Nerves frequently are freed for a long distance If, then, their central intrinsic blood vessels thrombose, as they very likely will, the segment of nerve walled off by the tantalum will necrose The real essential for

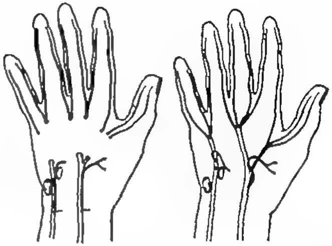


FIG 305 To overcome a gap between nerve ends in the palm, the motor branch of the median or ulnar nerve is spared by just splitting up from the main nerve to a distance equivalent to the gap (arrows) The main nerve (by freeing, flexing joints, etc.) is then drawn down to overcome the gap

a nerve juncture is not a smooth exterior but accuracy of sheath suture and placing the nerve in a good vascular bed of normal tissue. It is better to excise thoroughly the surrounding cicatrix en bloc and displace the nerve laterally to a good bed, or swing fat or fascia under it, than to expect foil to shove outwards to withstand strangling by surrounding scar cicatrix

Tantalum may be inert chemically, but it is, as any other metal, irritating mechanically in the ever moving tissue, especially opposite a joint. From this, the tantalum is often found to be fragmented and surrounded within and without by cicatrix. Many nerves have regenerated in spite of it, but too many have not. There has been found strangulation, white necrosis, a palpable lump from excess of cicatrix and free fluid. In some, function returned on removal of the foil In others, resuture was necessary, this time very late Diathermy applied 2 cm. away would burn the nerve.

A B C D E

FIG. 306 Case J A. C. Accident June 1 1939 Arm was drawn between pulley and belt, fracturing humerus and tearing apart median ulnar and internal cutaneous nerves.

Rupture and repair of median and ulnar nerves in upper arm. With improvement except has clawhand. Tendon transfers to improve muscle balance.

August 14 1939, three nerves were sutured, overcoming gap of three inches in musculocutaneous, four inches in ulnar and five inches in median by rerouting and flexing all joints.

March 19 1941 a pulley tendon T and finger muscle balance operation was done.

The last check up before patient moved away was on June 13 1941 only three months after operation. Even though too early the condition was improved There was less clawing more opposition of thumb and more curvature of arches. Fingers extended some in distal two joints. The patient reported that the function of the hand was much improved. He stated that he could shoot a pistol and bring his thumb forward from the hand. Also he could use his knife and fork which he could not do before. He picked up articles more easily and could dress himself better The grip was stronger and fingers less clawed.

(A and B) Taken March 17 1941 show the deformity preoperatively

(C D and E) Taken April 22 1941 only one month postoperatively show beginning improvement in position.

After 18 months have passed following nerve suture, if opposition of the thumb or muscle balance of fingers have not recovered, as happens in one-third of the cases, tendon transfer for these is indicated.

Special Procedures. OVERCOMING GAPS IN NERVES Frequently, on first sight it appears that the nerve ends cannot be brought together Normally, the nerve lies in a soft bed and has a certain amount of slack. By dissecting back along the nerve from the surrounding tissues, the nerve ends will yield several millimeters if small or one-half inch if large. A nerve should never be stretched beyond a certain degree which is safe, because multiple axones will break within it and there will be internal hemorrhages throughout its length, which are later followed by a scar reaction and loss of nerve function Also, by traction the nerve may be even evulsed from the cord. Frequently, however, considerable length can be safely gained by flexing the joint above and exerting just enough traction to drag the nerve through the tissues until its normal tension is reached in the new position of flexion The yield will not be enough to disrupt the motor branches, which are slackened by this maneuver This is especially useful for the median nerve in the forearm A tendon stripper can be used on a nerve where there are no branches. If there is still insufficient slack to bring the ends together the adjoining joint is flexed, and if this is insufficient the joint above and the joint above that until, if necessary, all of the joints up to the shoulder are in flexion. A nerve will not strip that length through the tissues, so one must make various incisions along the length of the nerve to free it in the vicinity of each joint.

If too long a length of nerve is freed from its surrounding tissues, that portion of the nerve must act somewhat as a nerve graft It has only its own internal blood vessels, which are insufficient. Return of function in it may be delayed for three or four months. Therefore, along the length of a nerve, when stripped, enough tissue should be left adherent for blood supply

In drawing a nerve along to gain slack we should be careful to protect its branches. Often it will be necessary to dissect these

up and out of the nerve trunk for varying distances with the back of a pointed scalpel Nerve ends brought together by flexing joints should be protected from being pulled apart by partially encasing the limb in plaster of Paris Flexion of the shoulder can be maintained by tying the hand to the opposite shoulder and the elbow to the side To gain length high in the nerve the clavicle or a segment of it may be removed, and the scalenus anticus may be severed so when the arm is flexed across the chest the nerves will take a short cut. Flexion of the neck is maintained by a strap from a plaster band about the head to around under the axilla. Flexion of the joints should be maintained for one month, after which the joints of the limb should be gradually extended a little at a time, each time adjusting a restricting splint, so the nerve will have time to grow long enough instead of being stretched In the usual case of moderate flexion two weeks is sufficient time to extend the limb gradually, but when multiple joints have been strongly flexed a month or more should be taken It will be found that other tissues will have contracted and will then act as a natural checkrein to extension and will yield by degrees The tension in drawing out a nerve does not all come on its juncture, for it has also become attached to the surrounding tissues If a nerve is sutured at the wrist, it is better to overcome the gap by flexing the elbow instead of the wrist as then the traction, on gradual extension will come less on the suture line Too great traction steadily applied to a nerve results in paralysis lasting from a month to permanently so when using splints this should be avoided.

Another method of gaining slack in a nerve is to transplant it to where it can make a shortcut across a joint Methods of doing this have already been discussed under the individual nerves

By the above means repeatedly gaps in either median ulnar or radial nerves of 5½ inches or 14 cm., have been overcome as shown by recovery of function and absence of separation between two tantalum wire markers on the nerve ends If a nerve is left on a stretch it will, like skin, be white from ischemia and become reduced to a fibrous cord The distal portion of the nerve when kept overstretched, shows more degeneration than does the proximal portion Experiments have been made that show that more than a 10 cm gap in a nerve cannot be overcome by flexing the joints and then allowing them to extend gradually I believe, however, that four weeks, instead of three, should elapse before commencing gradual extension Also, as a joint is allowed to extend gradually, it should not be kept on an extension strain by a turnbuckle as that would give continual ischemia of the nerve Instead, a checkrein should be used which would allow the degree of extension desired, and, also, give freedom to flex intermittently, so as to flush the nerve tissues with blood supply For this snubbing effect malleable splints are used for elbow and wrist, and there is no restricting bandage to prevent voluntary flexion of the limb in case the nerve pains Only occasionally is it necessary to resect a bone to allow nerve ends to be brought together, such as the humerus for suture of the brachial plexus If there is more of a gap in a nerve than can be readily overcome, free nerve grafting offers a good chance for success In the small nerves of a hand these work splendidly, but for the larger nerves in the forearm, cable grafts should be used so that the nerve strands will be nourished through and through. Details of nerve grafting are described at the end of this chapter

Another method of overcoming a gap in a nerve is to free the nerve well, flex the joints and suture the neuroma and glioma together After a month, the limb is gradually extended drawing out the nerve, and when the operation is then repeated there will be found sufficient slack for suturing

Still another method based on the tendon suture is to place stainless steel wires like

tendon sutures, one in the glioma and one in the neuroma, to draw the nerve ends together gradually The wires are brought out of the skin in opposite directions and pulled mildly but continually by light rubber bands to a piece of adhesive plaster fastened to the arm The nerve grows longer as can be checked by x ray

FREEING NERVES. A nerve encased in cicatrix or callus on being dissected free shows a narrowing from strangulation. Its sheath should be slit longitudinally in several places so it can expand First, however, it is well to inject the nerve hypodermically with salt solution until it is tight to balloon out the fibers in sheath and break up internal adhesions If the region of the nerve is cicatricial it can be inspected by making a longitudinal cut in it. Several such cuts can be made, preferably using the back edge of a pointed knife, but if much cicatrix is present it is better to excise it all and suture the nerve end to-end. If the nerve merely has been compressed, function may return at once. If, though, the constriction is extreme the nerve will have undergone Wallerian degeneration distal to the constriction and it will take just as long for return of function as if the nerve had been cut and sutured, for the axones of the proximal end must grow all the way down

PARTIAL NERVE INJURIES A nerve that has been near the course of a missile, but not hit, may show a fusiform swelling called pseudoneuroma of attrition. If it is from thickening of the connective tissue between the nerve bundles, usually there is natural recovery without excision and suture though one must judge the degree of cicatrix to ascertain which is the better course A nerve may show a notch with a nodule above and below This indicates partial severance and separation of the severed fibers. First, the nerve fibers should be split, preserving those that are still intact. Those terminating in the nodules should be trimmed off until good fibers present, and then sutured together This will necessitate splitting up and down the nerve and buckling the fibers which have remained unhurt. The same procedure is followed when a nerve shows a neuroma on one side, though here it is more likely that some fibers have found their way through the neuroma.

NERVE TRANSFERS. By this is meant suturing end to-end one nerve or part of a nerve to another It would, of course, be absurd merely to implant the end of a nerve between the fibers of another End-to-end transfers are just as successful as are nerve sutures, and are occasionally useful If too great a length in an important nerve is lost for repair, its distal segment can be transplanted into an adjoining nerve. This is practical, however, only when it is done high in the adjoining nerve before the nerve bundles have become arranged into funiculi, each having a special function. Part of the nerve should be cut squarely across and sutured to the distal segment of the paralyzed nerve. An excellent result was obtained from nerve transfer in a personal case in which a man's shoulder had been hit by a falling tree, evulsing various nerves about the shoulder and resulting in amputation above the elbow The three useless nerves in the amputation stump were drawn out, split, and attached to the distal segments of the circumflex, suprascapular, and long and middle subscapular nerves Function returned to all their respective muscles, so that now he efficiently manipulates an artificial arm (Fig. 481)

NERVE GRAFTS

DISCUSSION It is often questioned whether or not free nerve grafts are of practical value, and on this there is considerable difference of opinion ranging from the conviction that they are useless to the belief that they are successful In this book an attempt is made to contribute data from both our experimental and our clinical experience with autogenous nerve grafts.

Autogenous grafts of various kinds in

cluding the so-called prepared grafts were made in cats by Joseph H Boyes in a series of experiments. These we later checked microscopically to determine the down growth of axones

grafts that many useless, illogical methods of nerve joinings have been in common use which could not yield good results Thus nerve junctures have been made by end to-side implantation, by turning down nerve

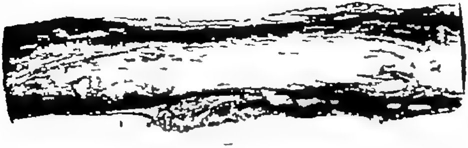


FIG. 307 Low power photomicrograph of a fresh autogenous nerve graft in the sciatic nerve of a cat four weeks after the operation. To the left is the proximal nerve, to the right the distal nerve. Between the two bits of sutures lies the graft. The new axons stain black. The gradually decreasing number as one approaches the distal end is apparent. (Courtesy Amer Jour Surg. 44 64–75 No 1 1939)

flaps, by sutures at a distance with catgut strands or a segment of blood vessel between, none of which make an end to-end union of the axone bundles Also, nerve junctures have been wrapped in Cargile membrane or some other foreign body or placed inside a segment of blood vessel, which effectively blocks blood supply from surroundings and adds excess of scar tissue where it will do most harm. Smearing with vaseline provokes a very bad tissue reaction. Inaccurate suturing and leaving a nerve suture in a bed of scar tissue instead of displacing it into normal soft tissue will result in strangulating cicatrix at the juncture. Therefore, the technic of suture should be weighed in evaluating the results from nerve grafting

Also, in a series of 32 autogenous nerve grafts done previous to 1937 by the writer in 22 patients, the results are listed.

When a nerve is cut the nerve trunk swells just above the severance, as each axone splits into many fibrils, each of which grows downward seeking the distal nerve end Thus, bountiful Nature provides 50 times the normal number of nerve fibers in hope that enough will find the way In the lower portion of the nerve which undergoes Wallerian degeneration, protoplasmic strands known as bands of Büngner form through the length of the nerve and act as pathways for the axones that grow down from the proximal portion of the nerve. In placing a free nerve graft there are necessarily two connective-tissue barriers, one at the proximal and the other at the distal juncture of the graft and nerve, through which the axones must penetrate. Our nerve suturing, therefore must be accurate to minimize these barriers for the degree of regeneration is in direct proportion to the accuracy of the union

It should be kept in mind in judging from the literature the value of nerve grafts that many useless, illogical methods of nerve joinings have been in common use which could not yield good results.

The many methods of overcoming gaps in nerves have already been described, and also nerve and tendon transfers

Failure of these methods leaves free nerve grafting as the only procedure available Therefore, its limitations and its values should be known

LITERATURE. Following the first description of the use of a nerve graft by Albert in 1878, a few isolated case reports ap-

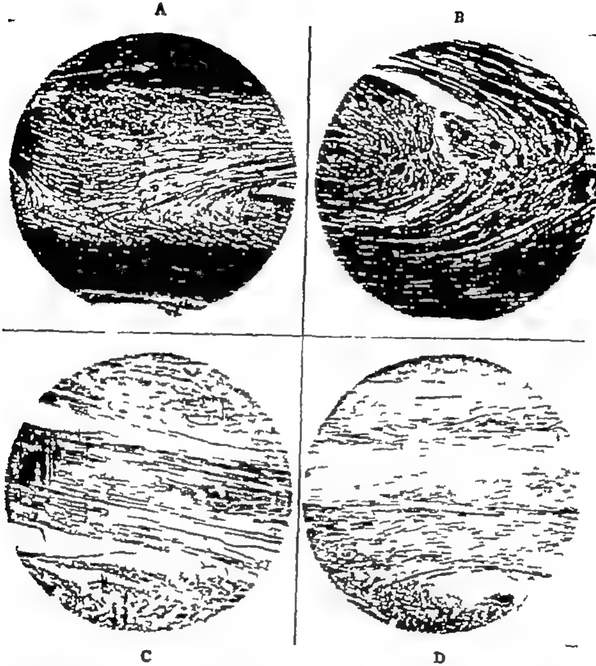


FIG 308 (A) A higher magnification of Fig 307 showing the proximal suture line. A bit of suture appears at 3 o clock.

(B) A section of the proximal suture line of a fresh autogenous graft in the sciatic nerve of a cat six weeks after the operation. At the lower edge are seen the coarse fibers of the proximal nerve nearer the center the fibers have become turned back in their course and at the left center some have completely reversed direction. The many spiral tubes called Perroncito apparati are an indication of obstructed growth, in this case due to folding back of nerve tracts *an example of poor approximation.*

(C) A section through the mid portion of a degenerated nerve graft in the sciatic of a cat four weeks after operation. The proximal nerve is to the left. Note that the central core has fewer fibers and that it still contains necrotic products because the graft has not yet developed a good blood supply in the central portion This explains the failure of grafts of large diameter

(D) A section of the distal suture line of a degenerated nerve graft in the sciatic of a cat four weeks after operation showing nerve fibers crossing the scar joining the nerve graft to the peripheral nerve. A bit of suture at 5 o clock marks the level of the anastomosis. (Courtesy Amer Jour Surg., 44 64-75 No. 1 1939)

peared in the literature, but it was not until the time of the First World War that reports were made of any appreciable number of nerve grafts, together with their end results. Platt's report in 1919 of a series of 20 cases of nerve grafts with complete failure in all gave rise to the note of skepticism among British surgeons which has since pervaded the English literature on the subject. In this series, however, it should be noted that only single nerve strands were used instead of cable grafts, and these were enclosed by fascia or vein.

Huber concluded that experimentally autografts were successful and, though some regeneration occurred through other types

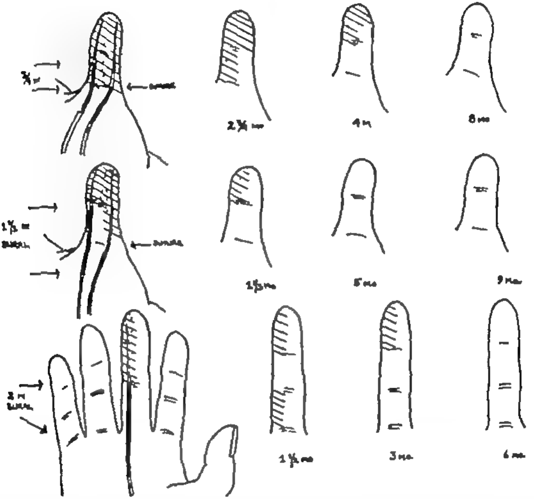


FIG. 309 (*Upper Row*) Case A. S. Nineteen months previous a hand saw lacerated across the proximal crease of the thumb. Infection followed, resulting in ankylosis of the proximal joint and loss of the flexor tendon and nerves. The contracture was relieved by zigzagging the scar in the web and repairing the nerves. The nerve to the radial side was sutured while that to the ulnar side was repaired by a free graft taken from the same nerve trunk higher up. Sensation returned to the pulp in eight months.

(*Middle Row*) Case R. B. Six months before a broken bottle had lacerated the right thumb severing both volar nerves and the flexor tendon. The resulting flexion contracture was relieved by plastic swinging of skin flaps. The nerve to the radial side was sutured at the proximal crease and a 1¼ inch gap in the nerve to the ulnar side was closed by a free graft from the sural nerve of the right leg. Sensation returned on the radial side in one and one-third months and on the ulnar side in nine months.

(*Lower Row*) Case J. D. Five and one half months after an infection of the long finger had destroyed the nerve to the ulnar side of the finger over a distance of two inches, the nerve was united by a free graft from the sural nerve. Sensation returned in six months. (Courtesy Amer. Jour. Surg., 44: 64–75, No. 1, 1939.)

of fresh grafts as well as preserved grafts the degree of regeneration in these was much less than through fresh autografts

Cajal and Forssmann postulated a chemotactic influence in the degenerated nerve which attracted the newly growing fiber from the proximal stump although Dusti and Huber failed to find basis for thi theory

Balance and Duel used fresh and pre

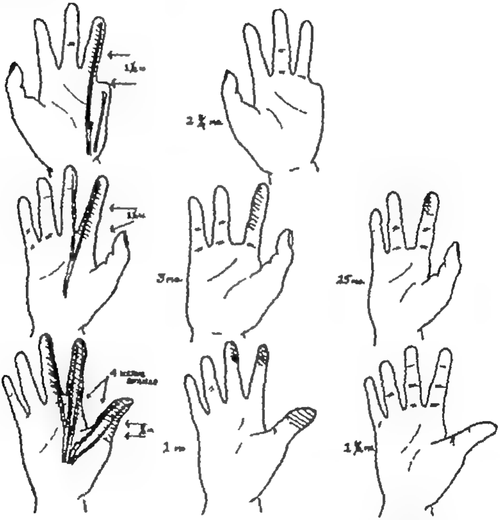


FIG. 310 (*Upper Row*) Case P L. Three years and two months after a circular saw had amputated the little finger and severed both tendons and one nerve of the ring finger a 1½ inch gap in the nerve was bridged by a free graft from the nerve to the stump of the adjacent little finger *Sensation was complete in 2¾ months.*

(*Middle Row*) Case L. S. Seven months after severe tenosynovitis destroyed the right long finger and severely crippled the hand and four months after the wounds finally healed a 1½ inch gap in the volar nerve to the ulnar side of the index finger was replaced by a free graft from one of the nerves of the amputated long finger Sensation returned rapidly up to a time two years from operation when a small area of anesthesia was still present on the tip. Atrophy of the skin cleared, however and sweat glands again functioned in this area.

(*Lower Row*) Case F LaP Ten weeks previously the flexor tendons in the right thumb and index finger and five nerves were severed when she fell on a milk bottle Four nerves were sutured, but that to the ulnar side of the thumb was too short. Therefore, a ½ inch segment was removed from its proximal end and used as a free graft to join this nerve. Sensation was complete in 1¾ months (Courtesy Amer Jour Surg., 44 64–75 No. 1 1939)

pared autografts in repair of the facial nerve and reported their results in a series of articles from 1931 to 1936 In experiments on monkeys they reported that they had obtained regeneration in prepared, that is, previously degenerated, nerve grafts, in one-half to one-fourth the time necessary for that in fresh autografts. This we do not believe because of our own experimental findings and those of Bentley and Hill in 1936

OUR EXPERIMENTAL WORK To deter

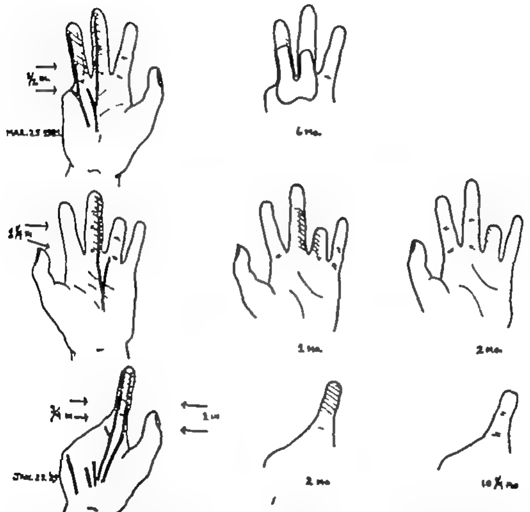


FIG. 311 (*Upper Row*) Case A. J Six months after the right hand had been crushed in a fly wheel exploration showed the nerve to the radial side of the ring finger destroyed beyond repair and a ¾ inch gap in that to the contiguous side of the long finger A free nerve graft was taken from the proximal portion of the more severely damaged nerve to the ring finger and the whole area was covered by a previously prepared tubular pedicle from the abdomen Six months later sensation was present over the complete area of the long finger

(*Middle Row*) Case H. S Three and one half months after a saw lacerated the left hand, severing the nerve on the ulnar side of the long finger and amputating the tip of the ring finger the stump of the ring finger was revised and a 1¾ inch gap in the nerve to the long finger was filled by a free graft from a nerve to the ring finger stump. Sensation returned in two months.

(*Lower Row*) Case E. M D Five months after a buzz saw cut across the hand obliquely from the base of the fifth metacarpal to the side of the index finger the cicatricial index finger was amputated through the middle joint and ¾ inch and one inch gaps in its two volar nerves were repaired by free grafts from the adjoining volar nerves in the palm Sensation was complete in the stump of the index finger in 11 months (Courtesy Amer Jour Surg 44 64–75 No 1 1939)

mine the regeneration following fresh nerve autografts compared with that following predegenerated nerve grafts, two series of cats were studied.

In the first series four cats were used. In each a 2 cm. length of sciatic nerve was cut out, reversed end for end, and sutured back into place. After intervals of two, four, six and nine weeks respectively, the cats were killed and longitudinal microscopic sections of each nerve and graft were studied.

In the second series of three cats, the sciatic nerve was first severed and degeneration of the distal portion was allowed to progress for two weeks. Then, in each a segment from the distal portion was cut out, reversed end for-end, and sutured into continuity with the nerve just as in the first series. The specimens were examined, one

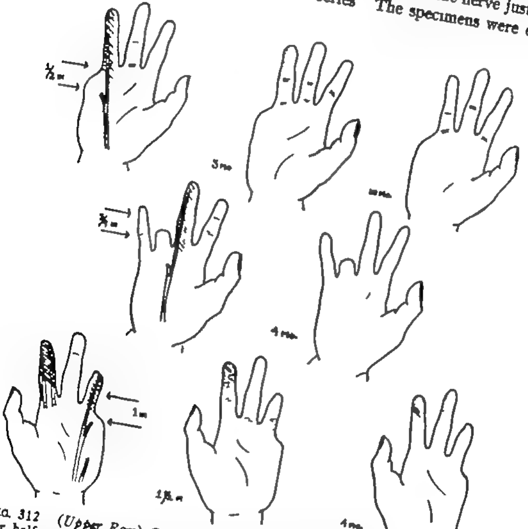


FIG. 312. (*Upper Row*) Case O. E. Eight months after an airplane propeller half severed his right hand, a ½ inch gap in the volar nerve to the ulnar side of the ring finger was closed by a free nerve graft from an adjoining stump of the little finger. Sensation was complete in ten months.

(*Middle Row*) Case H. D. N. Sixty-nine days after a steam shovel had amputated the ring finger and removed a segment of the volar nerve from the adjoining side of the long finger the ¾ inch gap in the nerve was bridged by a free graft from the radial volar nerve of the amputated finger. Anesthesia to cotton touch and pinprick left the long finger in four months.

(*Lower Row*) Case D. E. Six months after a circular saw lacerated the hand and after a severe subsequent infection, the nerves to the index finger were sutured at the level of the middle joint and an inch gap in the nerve to the ulnar side of the ring finger stump was filled by a free graft taken from the volar nerve to the little finger stump. Sensation was almost complete in four months. (Courtesy Amer. Jour. Surg., 44: 64–75, No. 1, 1939.)

in two weeks, another in four weeks, and the third in six weeks after operation

It was found that in two weeks in both the fresh and the degenerated grafts new nerve fibers had already penetrated the full length of the graft and were entering the distal nerve. At four weeks the fibers had increased in number in the grafts and had reached past the second suture line and well into the distal nerve At six weeks regeneration had progressed farther but myelin did not appear until the specimen obtained after the eighth week.

We concluded that there was no difference in the rate of growth of nerve fibers through fresh and predegenerated nerve autografts.

It is interesting to note that the regeneration of nerve fibers was largely in the peripheral zone of the grafts. Here surrounding lymph penetrated sufficiently to maintain vitality, while the central portion of the graft showed some necrosis This argues for either small or cable grafts instead of thick ones

Clinical Report and Discussion In

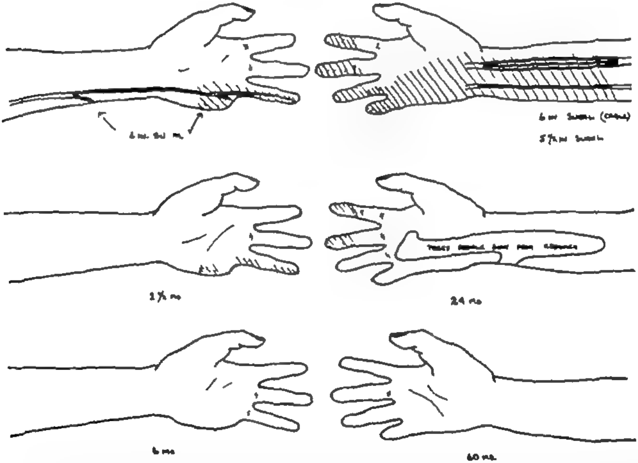


Fig. 313 (*Left*) Case J B K. Eight months after a laceration of the wrist from a broken windshield and subsequent infection had resulted in an amputation of the little finger and loss of the ulnar nerve a six inch sural graft was placed in the nerve as in the diagram. In five months sensation to touch and pinprick could be felt throughout. The ulnar motor branch had not been sutured.

(*Right*) Case S T Eleven months after a blast from a shotgun and subsequent infection had gutted the right forearm of tendons and nerves and after good skin had been supplied by a tubular pedicle from the abdomen, the median nerve was repaired by a three-ply six inch graft from the sural nerve and the ulnar nerve was united by a single strand 5½ inches long Five months later flexor tendons were supplied to all digits, a "pulley" operation for opposition of the thumb was performed, and the radial nerve was sutured. Five years after the first operation sensation was present throughout. (Courtesy Amer Jour Surg., 44 64–75 No. 1, 1939)

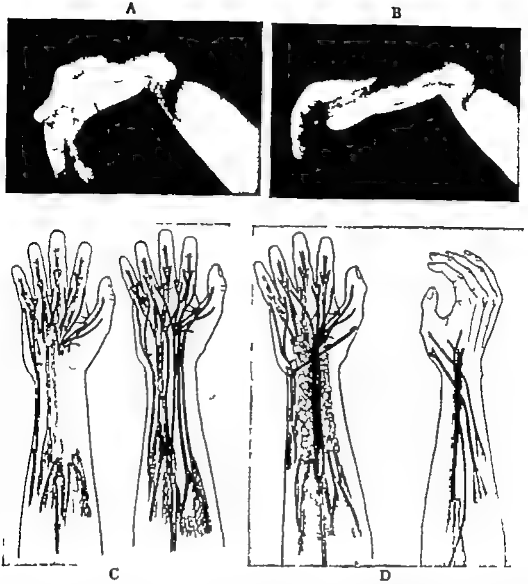


Fig. 314 (A to D) Case E. B., aged 23 Four years previously a buzz saw passed two-thirds through the carpus from the radial side, and a considerable length of the median and radial nerves and of most of the tendons sloughed out. The hand was totally useless. There was atrophy and absence of sensation except in the ulnar area, no pronation and supination and practically no motion, as shown in (A) and (B) which show the hand and wrist in full flexion and full extension, respectively

Operation (in two stages six months apart) (C) and (D)

Superficial and deep scar tissue were excised from both the front and back. A segment of ulna was removed to give pronation and supination and joints were placed in functioning positions. The only tendons remaining were the extensors of the fingers, the long extensor of the thumb and two roughened strands of flexors to the long and ring fingers. The deficiencies of the other tendons were made up by free grafts from the extensor tendons of the foot with their paratenon. In (D) the graft into the extensors of the wrist is shown to be surrounded with its paratenon. Another free graft was joined to the flexor ulnaris muscle in constructing a pulley operation for opposition of the thumb A wide sheet of paratenon fat was grafted from over the triceps tendon and interwoven about the flexor tendons to furnish mobility A six inch, three-ply nerve graft was used to bridge the gap in the median and another graft was placed to bridge that in the radial nerve, as explained in Fig. 314 (H) and (I) (Courtesy Jour Bone and Joint Surg., 10 1–25 1928)

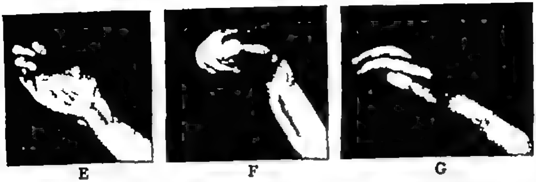


FIG. 314 (E to G) Result The hand became so useful to him that he changed his outlook on life and instead of becoming a teacher became a lawyer The thumb could spread two and one-quarter inches from the index finger and flexed until its distal joint was at 97 The grip measured 20 kilograms good sensation returned throughout and he could use his hand for all of his ordinary needs. (Courtesy Jour Bone and Joint Surg 10 1–25 1928)

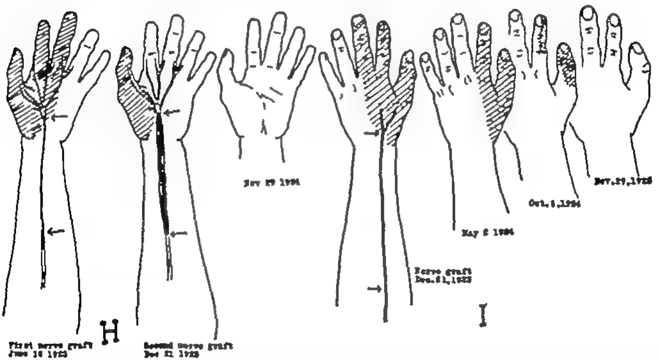


FIG. 314 (H and I) (H) Case E. B., aged 23 (Same case.) On June 18 1923 while joining the flexor tendons with grafts from extensor tendons of the foot, a single strand of sural nerve six inches long was grafted between the median nerve in the forearm and its distal end in the palm as shown between the arrows.

The anesthetic area diminished as shown so encouraged by this, two more strands of sural nerve from the other leg were grafted in six months later (December 21 1923) making a three-ply six inch graft.

In 11 months he felt light touch and pinprick over the entire area and identified a half dollar and called a knife a key At the end of one and one-half years stereognosis was good and although his fingers moved largely through six tendon grafts, he was able by feeling to tie his shoelaces, shave use a typewriter and pick up a match or large object with that hand.

(I) E. B (Same case.) On December 21 1923 while supplying tendon grafts for the thumb and extensors of the wrist a six inch graft of sural nerve was used to join the ends of the superficial radial nerve, as shown between the arrows.

The area of anesthesia shown is extensive for this nerve as the median nerve was also severed. The anesthesia to cotton wool (shaded) and pinprick (dotted) receded as shown by the dates on the diagrams. (Courtesy Surg., Gynec., and Obstet., 44 145–152 1927)

the following series of 32 nerve grafts done over a period of 15 years, we have endeavored to keep accurate preoperative and postoperative notes and to present a true picture of the results. Two additional cases

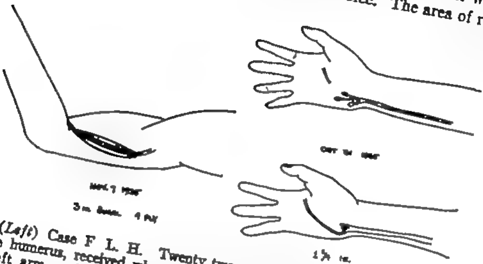


FIG 315 (*Left*) Case F L. H. Twenty two and one-half months after a compound fracture of the humerus, received when an oil drum exploded and wrapped its ends around the patient's left arm, and five and one half months after all osteomyelitis had healed, the musculospiral nerve was bridged by a four ply cable graft three inches long from the right sural nerve. Only an inner slip of the triceps had remained innervated. Eighteen months later anesthesia disappeared from the hand and voluntary motion was present in the extensors of the wrist and extensor pollicis longus. Examination three years after operation showed absence of anesthesia and good power to extend fingers and thumb even with wrist passively held dorsiflexed, but only a little of voluntary dorsiflexion of the wrist. The nerve pathway for dorsiflexion of the wrist was evidently mechanically missed by the down-growing axons, as it is the only nerve branch that did not regenerate and this branch of the radial nerve is usually the first to regain function.

(*Right*) Case T S Four years before, he fell on a glass, severing the ulnar nerve and flexor tendons to the ring and little fingers and opening the wrist joint. Infection followed an attempted primary repair and lasted two months. At operation on October 31 1935 (performed at meeting of American College of Surgeons) the little finger was amputated, including its metacarpal. Its extensor tendon was transferred to the adductor of the thumb, its flexor to the interossei of the ring finger and a 1¼ inch gap in the deep motor branch of the ulnar nerve was closed with a graft from one of the sensory branches of the ulnar Twenty months later the interossei recovered and their atrophy had disappeared. He could adduct the straight thumb to the same degree as in the opposite hand. (Courtesy Amer Jour Surg., 44 64–75 No 1 1939)

which could not be followed postoperatively are not included. The technic used was uniform accurate perineural or sheath suturing with the finest silk and without any intubation by free fat, membrane or foreign body placed around the juncture. The nerves sutured were, wherever possible merely placed in soft vascular tissue as free from cicatrix as possible.

Grafting was used only where the methods of achieving end to-end union were exhausted or were inadvisable Only those nerves were sacrificed for grafts whose function was of less importance than was the function to be gained. The sural nerve from the center of the calf was usually the graft of choice. The area of resulting anesthesia from loss of this nerve is small, if any, and patients as yet have not complained Occasionally a part of some other nerve was available because an amputation distal to it had rendered the nerve function less. It is neither necessary nor justifiable to sacrifice motor function to procure a nerve graft. Sensory nerves as grafts have been shown to convey motor or sensory axones equally well when placed in the normal direction or when reversed end for end. The sural nerve is nearly always

available It is just beneath the midvein of the calf, in the upper part of the calf it is under the deep fascia and in the lower part is superficial to it. Of other available sensory nerves the cutaneous branch of the radial, if severed, often leaves a most tender neuroma. The internal cutaneous and sensory branches of the femoral are rather small The long saphenous, if removed, causes some anesthesia. The sural, therefore, is the nerve of choice. Almost a foot of this nerve is available from each calf, allowing ample material even for a cable graft into a fairly thick nerve.

In our series the results are uniformly good in all of the cases that could be traced, apparently for the following reasons in this series the nerves grafted were either small in diameter (as the facial nerve or nerves in the hand) or if larger, cable grafts were used made up of multiple small strands of nerve grafts amounting in the total cross-section to the size of the nerve itself These slender stranded nerve grafts were readily kept nourished through and through merely by lying in the surrounding lymph until they acquired a blood supply of their own In contrast, a nerve graft which is large in diameter such as the median or sciatic would not be nourished by surrounding lymph except in a thin peripheral zone, and its central portion would undergo necrosis well before its new blood supply would be established. The same is true of tendon grafts. Those larger than flexors in the hand undergo central necrosis Thus small nerve grafts and cable grafts survive while thick nerve grafts undergo much central necrosis A nerve graft can hardly be expected to yield as good or as quick a result as a nerve suture because there are in the case of a graft two suture lines, each of which forms a cicatricial obstacle through which the axones must penetrate. A nerve suture obviously has only one such line. Even so, however the speed and degree of regeneration following nerve

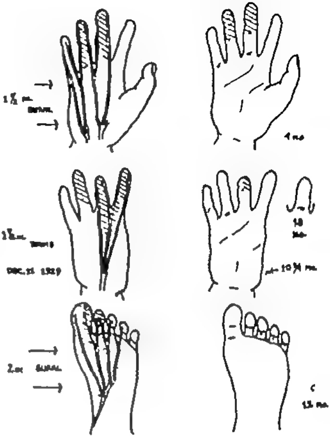


FIG. 316. (*Upper Row*) Case A. T Four and one half months previously a saw cut the right palm, severing tendons and nerves. The 1½ inch gaps in the volar nerves to the second, third, and fourth clefts were closed by free grafts from the left sural nerve. In four months sensation had returned except over the area shaded above, after which he did not return.

(*Middle Row*) Case W A. D Nine months after the right hand was caught in a bale cutting machine, amputating the thumb and a portion of the long finger and severing all the flexor tendons except the little, and seven months after the infection had subsided, the nerves to the index and long fingers were repaired by three free nerve grafts from the cut segments of the nerves in the palm and the two nerves to the thumb. Sensation was present throughout 18 months later

(*Lower Row*) Case E. W Ten and three fourth months previously she stepped on a broken bottle lacerating the sole of the left foot. At operation a gap of 1¼ inches in the flexor hallucis longus tendon was bridged by a free tendon graft. Each of three branches of the internal plantar nerve had a two-inch gap in it which was filled by free grafts from the sural nerve of the opposite calf One year later sensation was present throughout and motion had returned to the great toe. (Courtesy Amer Jour Surg., 44 64–75 No 1 1939)

grafts have compared fairly well with those after nerve suture.

In our series of 32 grafts, three were of the cable type and one of the facial nerve was branched into three. The sural nerve

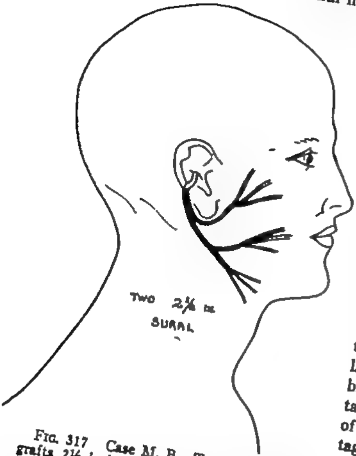


FIG. 317 Case M. B Two free nerve grafts 2½ inches long one of which was branched, were used to repair a facial nerve which had been invaded by a tumor of the parotid gland. Some voluntary motion first appeared in six months, increased in nine months, and in 17 months symmetry of the face was regained. The tumor later recurred and was excised with the nerve graft en bloc. Sections showed that nerve fibers had grown through the graft into the distal portion of the nerve. This is the first case in which a free nerve graft was used to repair the facial nerve. (Reported in detail in Arch. Otol., 25 235–259 1937) (Courtesy Amer Jour Surg., 44 64–75 No 1 1939)

was the source of graft in 17, and other nerves, as in amputation stumps, in 13 In two instances a short, thin segment from a higher part of the same nerve was split from the nerve and used. The length of grafts used varied from one-half to six inches.

Since the above compilation, our series of nerve grafts has been increased to 81, with similar results

CONCLUSIONS. 1 A series of 32 autogenous nerve grafts in the human is reported, with return of some function in all and a considerable degree in many

2 Experimentally in cats the axones were demonstrated to grow through the grafted nerve segment and on down through the nerve.

3 Prepared grafts have no advantage over fresh grafts.

4 A nerve graft to be successful should be small in diameter or made as a cable graft of many small strands, so that each strand will be nourished through and through by the circulating surrounding lymph until it has acquired its own blood supply

Bentley and Hill independently, based on their own experimentation, arrived at similar conclusions. In cats they successfully bridged by nerve autografts for 3 cm., obtaining anatomic and physiologic continuity of the nerve They disclaimed any advantage of the predegenerated nerve graft, or any difference in the result when using them for fresh grafts. They found that the scar at the second suture line acted as an obstacle to the down growth of the axones but when the suturing was done accurately, the hindrance to down-growth was very slight. They found that nerve homeografts were only moderately successful and showed considerable foreign body reaction. Tarlov showed that nerve grafts are largely vascularized longitudinally from their ends in a process taking three weeks. He, also, found that thin bundles of nerves became vascularized and innervated more readily than thick bundles.

Conclusive proof of return of function following auto nerve grafts of small diameter or cable grafts by regeneration instead of overlap has been checked in many cases by blocking the nerve in question or the other nerves to the hand, and by the

localizing method of Shreve as stated under "mode of recovery" Other proofs are in the return of face movements after facial nerve grafts, return of voluntary extensors of wrist one year after an eight centimeter, two-ply cable graft from an intercostal nerve of the radial nerve high in the upper arm (Chenaweth), and after a three inch graft to the ulnar nerve, return of sensation in the little finger which is an isolated area (Howard)

Recently, in studying the results of 52 nerve grafts that were followed through, Professor H J Seddon found that 67.3% of them yielded a useful return, and in 38.5% the return was as good as after nerve suture. The junctures were by plasma though by suture may have been more accurate His greatest cause of failure was from intraneuro fibrosis from surrounding cicatrix and he agreed that exactness of technique is a main factor He found the following available for grafts Internal cutaneous, 20 to 27 cm superficial radial, 20 to 25 cm., sural, 25 to 40 cm , and saphenous, up to 40 cm.

Grafting Larger Nerves. Larger nerves, if slit into several strands or opened out like a ribbon, will live as they will then be nourished through and through, while one grafted intact will undergo central necrosis. Capt. S Selverstone used a live nerve graft with blood supply For a large defect in forearm of both median and ulnar nerves, the ulnar nerve was cut high in axilla and joined to median nerve at elbow Tinel's sign advanced up the ulnar nerve to the axilla. Six months later the ulnar nerve was swung down and sutured to the median at the wrist. Three months later, Tinel's sign was to the end of the palm. When I last saw the patient, four months later still, sensation returned. It did not leave on blocking the radial nerve. Later, at operation, touching of the branches of the median nerve in the hand was felt. The method is encouraging

Painful Neuromata In amputation stumps, after three months, painful neuromata may cause such hyperesthesia and exaggerated Tinel's sign as to render the member unfit for work Many curly axones have grown out into the surrounding tissues, and when these vibrate from tapping there is pain Some neuromata are caught in scar If close to the skin a sensitive whorl is visible there Many neuromata do not cause symptoms, and in most the hypersensitiveness fades away in two or three years as we rarely see cases that have lasted many years.

In the 12,000 amputees in the army of World War II painful neuromata were rare, evidently because a guillotine amputation was done first and later a reamputation through clean tissue. This argues that infection in healing causes painful neuromata.

For those neuromata requiring surgery the following routine procedure usually but not always results in relieving the condition. In a few unsuccessful cases, which are decidedly in the minority, there seems to be an unusually strong tendency of the nerves to regrow

On dissecting out the end of the nerve with its neuroma, and freeing it away from the cicatrix, a mosquito hemostat is lightly placed on the nerve a short distance above. The nerve is crushed, ligated, and cut off proximal to the neuroma. Ligation is done with fine silk or No 40 stainless steel wire, which is tied lightly so as not to cut through the sheath and still to enclose the axones, lest they again grow out into the tissues The contents of a hypodermic syringe loaded with absolute alcohol are then injected into the segment of the nerve between the ligature and the hemostat above, so as to balloon out the sheath, thus bathing the enclosed axones in alcohol. After a pause the hemostat is removed The object of the hemostat is to keep the alcohol in the terminal segment of the nerve, for if it be injected up the nerve without any block, not only may painful

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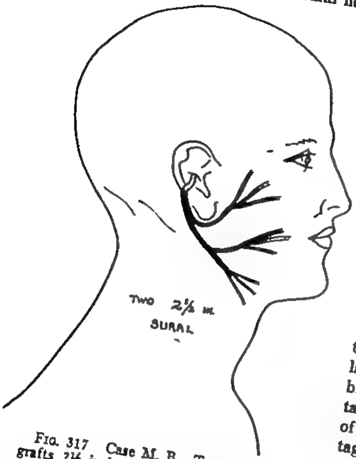

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neuritis follow but the alcohol, if in a finger, will backtrack down the branches of the nerve and cause a patch of necrosis in the skin. The end of a nerve is now grasped with a mosquito hemostat and thrust high into the soft tissues, where it will be away from any trauma. The value of even these limited alcohol injections is still to be proven. I now omit the alcohol

Painful Stumps and Scars. Exquisite tenderness and spontaneous pain in amputation stumps and scars are often not due to neuromata. A nerve end or twig may be caught in the scar and cause pain by strangulation or by being pulled by the scar on movement, or the scar itself may be so dense and attached to the bone as to be painful Amputations from crushing show this, and unless reamputated high enough beyond all damaged tissue the complaint will persist. In some cases, after several reamputations, operations on neuromata, etc., the persistence of pain suggests that a pain-habit pathway has been worn to the brain, or that the central sensory neurone has been affected. (See Painful Amputation Stumps, in Chapter 17.)

Irreparable Nerves. If the nerve is irreparable—such as in poliomyelitis, loss of nerve, or destruction from evulsion from the cord, or a nerve which has been torn apart—muscle and tendon transfers may be used to restore lost function, and in some joints should be arthrodesed in positions of function For these procedures the reader is referred to Chapters 9, Tendons, and 11, The Arm in Its Relation to the Hand.

Neurotization Implanting a nerve into a paralyzed muscle at its normal point of entrance has been done experimentally New end plates have been demonstrated, and the muscle was found to be redder locally Even some reaction of the muscle was obtained. Results seem too inconclusive, however, to justify confidence in the practical usefulness of the method.

Even less encouraging is the implanting of a portion of active muscle into a paralyzed muscle.

Neurectomy for Spastic Paralysis. In spastic paralysis, a third of which are mentally defective, only those cases are worth operating upon who are over the mental age of five and so have enough mentality to cooperate in the muscle training afterward Of the various types of spastic paralysis, only those lesions of the pyramidal tract in which the upper neurone alone is involved and not the various coordinating nuclei and tracts of the brain are suitable for neurectomy This eliminates cases of Little's disease, athetosis, ataxia, chorea, progressive spastic paralysis, and hemiplegia. Its use is limited to cases ranging from definite deformity to mild contracture, and caused by loss of the inhibitory action of the upper neurone, thus resulting in hyperactivation of the muscles by the lower neurone. There should be some muscle action in the opposing group

In early cases the spastic contracture can readily be drawn out by splints, and the limb when placed in the corrected position may go into the opposite contracture In this stage the contracture yields as it has not yet become fixed in the muscle by fibrosis, and the opposite deformity is possible because both muscle groups are hypertonic. In this early stage the deformity may disappear in the relaxation of sleep only to recur when the limb is activated as it is due merely to imbalance of nerve impulses, but later orthopedic treatment may be needed.

There are various muscle transplants tenotomies, tendon lengthenings, and arthrodeses, which give definite results, often transferring the powerful muscles to the weak ones or otherwise evening up the muscle balance.

In addition there are the neurectomy methods developed by Stoffel. His first plan was to resect in the nerve trunk the funiculi which controlled the spastic muscles. It was found that these funiculi in ascending

the nerves soon lost their pattern, due to various plexuses within the nerve itself Faradic stimulation of certain bundles aided in identification, but this was not sufficient Therefore, Stoffel's second operation of tracing the nerve to the muscle and there locally reducing or removing the nerve supply became the one of choice.

The object is to correct the muscle imbalance, but if too much nerve supply is removed the opposite deformity will be produced. On tracing the nerve to the muscle its various branches may be readily dissected out by using the old dissecting probe.

In the upper extremity, in contrast to the lower, the flexor muscles are more powerful than are the extensors. In spasticity they overpull their antagonists, causing deformity of flexion and pronation. At the shoulder is produced the deformity of adduction and internal rotation. The elbow becomes flexed and the forearm is drawn into pronation. The wrist and fingers become flexed and the thumb is adducted or opposed.

Neurectomy is rarely used at the shoulder, and in the elbow is not needed as some degree of flexion is not objectionable in the use of the arm. The usual neurectomy procedures are performed on the median and ulnar nerves.

Median Nerve. Here we have to correct excessive pronation, flexion of the wrist and fingers, and flexion of the thumb The nerve is uncovered just below the elbow where its muscular branches come off in the order above noted. Enough are severed, according to the severity of the case, to restore balance in the forearm muscles Usually more nerve supply must be removed from the pronator and flexor carpi radialis than from the flexors of the fingers

Ulnar Nerve. The nerve is exposed just below the elbow, taking enough of the supply from the flexor carpi ulnaris and a little from the flexor digitorum profundus In the hand, to decrease adduction of the thumb, the deep motor branch of the ulnar nerve is exposed deep in the palm, and its terminal branches are severed

Muscle transfers and tenotomies are more frequently resorted to for spastic paralysis in the upper extremity than is neurectomy, the latter being used supplementarily At the shoulder, Sever's tenotomy of the subscapularis is done, and in severe cases also of the pectoralis major, teres major, and latissimus dorsi For flexion of the elbow tenotomy is done on the biceps and brachialis anticus, leaving the supinator longus and forearm flexors for this motion.

In the forearm, pronation and flexion of the wrist are lessened by severing insertions of the pronator teres, pronator quadratus, flexor carpi radialis, and flexor carpi ulnaris. These muscles are then used instead in combination to produce supination and extension To supinate, if the pronator teres and flexor carpi radialis are transferred to the radius through a hole in the interosseous membrane, they will adhere. Mayer advises that these muscles be united and transferred subcutaneously about the dorsum of the forearm to the radius Similarly, according to the method of Steindler the flexor carpi ulnaris is passed subcutaneously across the dorsum of the forearm to insert on the radius. To extend the wrist the pronator teres and flexor carpi radialis can be transferred to the extensor carpi radialis and the flexor ulnaris to the extensor ulnaris The wrist may need a wedge resection.

Steindler advises tendon transfers for mild cases that relax on rest, but if the contracture at rest must be drawn out he adds Stoffel's operation If, though, it cannot be drawn out, it is necessary also to add tenotomy or tendon lengthening In severe contractures of the wrist with straight fingers, the wrist is resected, and to extend the fingers some flexors are transferred. If the wrist is straight and the fingers are flexed, the finger flexors are weakened by Stoffel's operation.

Arthrodesis of the wrist is rarely done for spastic paralysis because wrist motion is necessary for automatic movements of the digits.

For spastic opposition of the thumb, after first correcting the wrist, Burman strips the thenar muscles from the proximal phalanx and metacarpal of the thumb, severs the capsule of the metacarpophalangeal joint, and elongates the tendon of the long flexor of the thumb according to the needs of the case. For adduction of the thumb he strips the first dorsal interosseus muscle from the metacarpal of the thumb and divides the adductors. Treatment for the various types of intrinsic muscle imbalance may be found in the bibliography under this reference.

The bone block arthrodesis for opposition of the thumb (p 515) will hold the metacarpal well in place.

Following any of the above transfers, the arm and hand should be put up in plaster in the position opposite to the deformity, and maintained so for three weeks. The above should be followed by postoperative reeducation. These methods of tendon transfer *may be found in Chapter 9, Tendons.*

For *hemiplegia* a splint may be worn at night and for a week at a time by day to hold the wrist and fingers extended. Also, the wrist may be arthrodesed straight and the two joints of the thumb fused in moderate opposition

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9

Tendons

One of the most baffling problems in surgery is to restore normal function to a finger in which the tendons have been injured When we consider that a third of industrial disabilities are from injuries to the hands and that a successful repair of an injured finger tendon is a rarity, it is apparent that there are special attendant difficulties which cannot be overcome by the ordinary surgical procedure.

My first attempts at repair of tendons in the fingers resulted in immediate success, but as the succeeding days went by motion became less and less, until at the end of a few weeks it was nil The tendons had become firmly imbedded in scar tissue and had united to the surrounding finger in a solid mass Such failures as these were a stimulus to work out a method of treatment which would yield better functional results in these cases Primary repair of tendons is discussed in Chapter 12

MORPHOLOGY

The gliding mechanism of a tendon differs according to whether the tendon pulls straight or around a corner In the former it travels through paratenon, in the latter through a tendon sheath. Paratenon is specialized loose fat which fills in the space between the tendon and the immovable fascial compartment through which the tendon runs. It is quite different from short fibered subcutaneous fat as it is loose mobile, and elastic. The long elastic fibers running between the fascia and tendon are, when the tendon is at rest, curled and tortuous like a spring When the tendon moves in either direction these fibers straighten out long enough to allow free excursion Thus the tendon does not glide through the paratenon but is adherent to it and merely drags the loose elastic tissue first in one direction and then in the other Thus, the central part of the fat, which is adherent to the tendon, moves with the tendon, while the peripheral part, which is attached to the fascia, does not move. Examples of paratenon formation are seen in the volar or dorsal aspects of the lower part of the forearm just proximal to the tendon sheath formation and over the dorsum of the foot. In the palm for the flexors of the first three fingers is paratenon extending from the ulnar bursa to the sheaths of these finger tendons.

In the tendon-sheath formation, which is

merely an adaptation for a tendon to turn a corner, the tendon does not move through any greater amplitude of motion than it does in the paratenon formation It glides around a curve on a thin film of synovial fluid between two smooth synovial lined surfaces, just as metal surfaces in machinery glide on a thin film of oil

A tendon sheath consists of two layers of synovia, the visceral one enveloping the tendon and the parietal layer lining the fascial tunnel through which the tendon glides. These two layers are continuous with each other through the medium of a narrow mesotenon, just like the two-layered peritoneal reflection of the mesentery The mesotenon is so loose and filmy that it does not hamper the motion of the tendon It is always located on the longitudinally convex side of the tendon where it is away from friction, and along this aspect of the tendon most of the blood vessels are found. The friction-bearing or concave side of the tendon is mostly avascular and is harder, like a shoe, to stand wear

As the tendon glides to and fro the ends of the tendon sheath form in one or two prepuce-like, invaginating concentric folds or plicae. These two falciform plicae are zigzag in sagittal section, and pull out straight when the tendon is pulled in either direction. The inner layer of the tendon sheath which intimately invests the tendon is called epitenon, and the outer layer is called the sheath Small septa running into the tendon from the epitenon and separating the tendon bundles are called endotenon. The two-layered mesotenon bears the blood and lymph vessels which nourish the tendon itself and when the tendon is lifted from its bed the mesotenon stretches out to a thin transparent, vascular membrane several centimeters wide.

In the tendon sheaths within the fingers the mesotenon is reduced to the ligamenta brevis and longus, which bear the vessels Where tendons pull around the concave side of a limb, as in the fingers and wrist, they are held in their beds by annular ligamentous sheaths or pulleys that keep the tendons from bowstringing across the joints, and so losing their mechanical efficiency These sheaths in the fingers are not located opposite the joints, but are opposite the segments between and near the joints. They are smooth, being lined with synovial membrane to minimize friction, and are tough to withstand the force of the tendon. In our operations they should be preserved and especially should their gliding surfaces be protected

PATHOLOGY OF TENDONS AFTER INJURY AND INFECTION

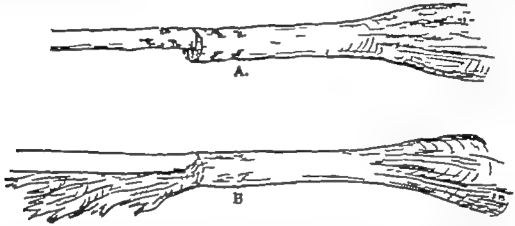
When a tendon is severed in a sheath its ends become smoothly rounded over and merely lie loose in the sheath making no effort to proliferate. When severed in paratenon, however, the end of the tendon and the surrounding paratenon proliferate in an attempt to reattach Tendon retraction is greater in the sheath than in paratenon.

If infection follows severance within a sheath, the tendon will become adherent and will show some proliferation and attachment of its ends. Infection in paratenon formation increases the proliferation and cicatricial attachment. In pyogenic tenosynovitis when drainage is established early enough so the infection does not penetrate through the epitenon into the depth of the tendon, a cure with good tendon function may be obtained If the tendon be exposed to the infection too long, however, it will puff up to three times its size and undergo necrosis in part or in whole and slough or be replaced with cicatrix.

Greatest damage to tendons is found in closed, firm tunnels, such as within a finger or under the annular ligament in the wrist. Here, when infected, due to swelling the tendon is held so firmly that it becomes ischemic and consequently necrotic and in

turn cicatricial A sloughing tendon is eventually replaced by a contracting cicatrix which attaches to the surrounding tissue and draws the joints into flexion The tendon sheath proliferates greatly and similarly attaches itself and contracts Such a firm cord cannot be drawn out by continuous traction Physiotherapy is useless The damage found at operation is always worse than expected

join its opposite end by sending out a pseudopodium, which may be an inch or two long and considerably thicker than the tendon itself This prolongation will attach itself firmly to whatever it touches and will anchor the tendon end If the tendon is severed where there is no gross paratenon, but merely a thin, slippery layer as seen in the palm, even here a thick, translucent, jelly like tube with walls one



A.

B

FIG. 318. If there is left an "unsatisfied" end of a tendon, or in suturing together a small and large tendon, part of the latter end is left exposed or "unsatisfied" (A) that part will grow principally from its epitenon a pseudopodium (B) which will reach out and attach itself to the surrounding tissues and contract, so that the motion of the tendon will be checked. (Courtesy Jour Bone and Joint Surg., 14 31 No 1 1932)

On severance of a tendon if it is free, the muscle contracts the distance of the amplitude of motion of that tendon or half the length of the muscle belly Up to two months following the accident the tendon ends may be drawn together and repaired by direct suture, but after that time it will be found that the muscle has become fixed in its contracture so it cannot be sufficiently stretched out. Extensor tendons in the hand retract less than flexors.

Tendons, like bones, degenerate from disuse They become thick, yellowish soft, shreddy, friable, and unfit for use as grafts Whenever a tendon is adherent at one place it will be found to be adherent from there distally

When a tendon is severed in paratenon formation it will make an attempt to attach itself to something or to reach out and

to two millimeters thick will soon extend out as a pseudopodium and attach. If the two ends of a severed tendon thus reach out and touch each other, they will grow together and eventually undergo contraction so that the continuity of the tendon will be reestablished This is Nature's way of rejoining tendon ends.

If a tendon end or part of a tendon end, not in tendon sheath, is free or "unsatisfied" it will by growth reach out and firmly attach itself, often to the detriment of the individual's manual ability, as such firm attachment may hinder function. In an end to-end suture of a small tendon to a large one, care should be taken to enclose the "unsatisfied" part of the large end or it will reach out and become attached to the surrounding tissues, preventing motion If one tendon becomes attached it will hold

back the common muscle which moves the tendons of the other fingers, and so will limit the action of all of the tendons. This is also frequently seen after amputation of a finger, the tendon attached to the stump has too short an amplitude of motion to allow full motion of the tendons of the other fingers.

When one flexor profundus tendon becomes adherent in the hand it will be impossible to flex the adjoining fingers completely and on attempting it there will be pain, cramps, and weakness If the examiner duplicates the condition in the other hand by holding the same finger in extension while gripping is attempted, there will occur a similar feeling and limitation of flexion of the other fingers The cure is not only to free the attached tendon in the palm, for it will reattach, but to remove it completely to well above the wrist. Because of interdigitation, the profundus tendon cannot be withdrawn from the forearm, but must be drawn up distal end first backward and out the forearm

An attachment of a tendon will limit the action of its antagonist, whether it be flexor or extensor, and so will result in a contracture. Tendons should never be sewed together over an amputation stump of a finger nor at operation should we leave loose or "unsatisfied tendon ends free to attach themselves A free tendon end should be imbedded in an adjoining tendon. Similarly, if we graft fascia, the cut edges of the graft being "unsatisfied will proliferate and attach, so should be turned in if this is not desired. The distal end of a flexor tendon left in a finger will, in the presence of sheath damage hematoma or infection, attach, contract, and draw the finger into contracture.

A tendon, following partial rupture or bruise, undergoes repair process in which it becomes swollen and soft. Frequently such a tendon, after one to three weeks, will rupture from some trivial strain, because the tendon softens during repair

ADHERENT TENDONS

There is a strong tendency following trauma or infection for tendons throughout their course to become adherent to their surrounding tissues, with resulting limitation of motion The same causes that result in stiffening of joints apply equally to tendons, as narrated in more detail in Chapter 7, Joints. Whenever, from trauma or infection, a hand is swollen or edematous there is much serofibrinous exudate throughout the tissues. If, then, the hand be kept immobile by splints or lack of use, this transudate, rich in proteid and fibrin, will seal the movable parts and this followed by fibroblastic proliferation will result in a congealed hand with adherent tendons and stiff joints. To avoid such a condition, which may take a year to subside or which may even be permanent, in all cases where there is edematous swelling with exudate, whatever be its cause, one should refrain from prolonged splinting or splinting of more of the digits than necessary, and should promote active full range motion early and continuously wherever possible. Lively elastic or spring splinting preserves motion Fresh tendon repairs, fractures, and acute infections may contraindicate the movement of certain parts, in which case one should always encourage movement of the adjoining parts Early efforts of prevention outvalue months of after treatment.

HEALING OF TENDONS

When two cut tendon ends are placed in proximity to each other or are held so by tendon suture, the following by weeks is the process of tendon repair

First Week. This is the week of the fibroblastic splint. Commencing at once a translucent jelly like substance joins the two ends in a soft fusiform swelling and connective tissue cells start at once to grow into this. The tendon ends become reddened and swollen for about one-half inch their length, due to increased vascularity

and connective tissue proliferation The connective-tissue elements in and about the tendon contribute to this early repair by growing out as fibroblasts into the homogeneous jelly like substance and soon contracting to connective tissue fibers This process comes not from the tendon cells but from the epitenon, tendon sheath, paratenon, and endotenon During this first week the tendon ends become joined by this swollen fibroblastic splint, formidable looking but devoid of strength. Proliferation of the cells within the tendon commences only after the fourth or fifth day

Second Week. This is the week of connective-tissue proliferation Swelling of the tendon increases to its maximum and there is much redness, vascularity, edema, and especially proliferation of the connective-tissue elements, which bridge the gap between the tendon ends but do not furnish strength. Through this connective tissue and jelly like mass ingrowth of tendon fibers and cells commence to be conspicuous by the eighth day, and between the tenth and fourteenth days is seen bridging the gap Until the ends of the tendon are bridged by tendon fibers of collagen, the juncture can be easily ruptured The fusiform mass of tendon juncture is continuous with the surrounding tissues, which aid the two tendon ends in furnishing vascularity

Third Week. This is the week of production of tendon collagen fibers. The juncture is still swollen and vascular, but is firmer and a little less red Tendon fibers have formed across the gap and increased mitosis of the cells between them can be seen extending from one centimeter back into each tendon end. The juncture which was quite soft in the first four days, and firmer in the second week, now has a definite firm feeling as the soft edematous tissue is being replaced by connective tissue and tendon fibers Already, at the juncture between the tendon and the surrounding tissue, a cleavage or separation is commencing to loosen for movement. By the end of the third week there is a fair degree of strength present, largely from formation of the strong tendon collagen fibers themselves Nelson Howard suggested that the long spindle-shaped cells within a tendon are flat and oval-shaped endothelial cells in the walls of longitudinal canals throughout the tendon and that they contain plasma—probably for lubrication The strong cords of collagen composing the bulk of the tendon are the nonvital products of connective tissue cells arranged parallel and longitudinally in response to stress of tension.

Fourth Week This is the week of resolution The swelling and vascularity decrease and the loosening of the tendon from the surrounding tissues already allows some degree of gliding By the end of the fourth week there is good strength in the juncture, though not quite equal to normal.

The process of repair in paratenon formation takes place faster and more luxuriantly than in sheath formation, as the vascularity from the surrounding tissues is greater and the proliferation of the paratenon itself adds strength.

Effect of Function. Functional activity of a tendon has much to do with its character of repair In response to tension on the tendon the fibers and cells within the tendon arrange themselves longitudinally with the tendon. If the muscle is paralyzed union of the tendon ends will be considerably delayed and feeble, and the tendon structures will not be arranged longitudinally Mason and Allen experimented on the effect of function on healing They found that the juncture of a functioning or mobilized tendon up to the fifteenth day is not any stronger than the juncture of the tendon which has been carefully protected by immobilization. They found, however, that it was more irritated, swollen, and adherent. From the fifteenth to the twenty first day after suture, both the active and the immobilized tendon improved in strength, but beyond that time the immobilized tendon did not increase in

strength, while the exercised one continued to strengthen in response to function. Active motion, commencing soon after suture, results in so much tissue reaction, proliferation, and adhesion that the tendon ends become bulbous, separate somewhat from

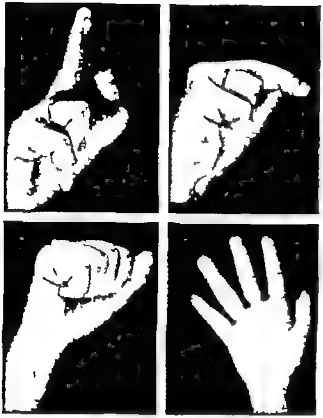


FIG. 319 Case A E. Two months previously on striking a basket ball with the fingers the long finger would no longer flex. The tendon had torn from the muscle in the forearm.

(*Top*) Position and limit of flexion of long finger Through the two transverse incisions shown the flexor tendons to the long finger were shortened.

(*Bottom*) Full motion resulted.

each other though still bound by scar tissue, and firmly attach themselves to the surrounding tissue The immobilized tendon shows the least irritative tissue reaction and attachment to its surroundings, so that the tendon which has been immobilized for five weeks gives the best appearance and shows the greatest degree of gliding

Functional activity during the first 15 days is apparently detrimental to the degree of gliding ultimately obtained. It, therefore, seems best after tendon suture to forbid exercise for from 15 to 21 days, then to allow restricted or guarded exercises for a week followed by more strenuous exercise Clinically this plan works well Only a little exercise is allowed in the third week, and on the twenty first day the stainless steel wire stitch is removed from the tendon which is now strong enough for moderate exercise.

Immediately after suturing a tendon the strength of union is no greater than that of the suture at the knot. The strength of the tendon itself drops somewhat to the fifth day, while the tendon is in the soft stage, but reaches its initial strength by the ninth day At the end of two weeks it will not stand much strain, but after the third week there is moderate strength. After the fourth week the danger of breaking is over and the more the tendon is exercised, up to a reasonable degree, the greater will be its mobility

PROCEDURES USED IN TENDON REPAIR

A compilation of the relative frequency of each procedure used in the repair of 3,500 tendons, the great majority of which were secondary and not primary repairs, showed the following

Freeing	41 per cent
Grafting	30 per cent
Suturing	18 per cent
Transferring	10 per cent
Lengthening or shortening	1 per cent

Freeing tendons tops the list, because when one tendon is repaired it is frequently necessary to free the adjoining tendons. Also, tendons are frequently freed following trauma or infection, fractures of phalanges and metacarpals and as a late secondary procedure after tendon repair

PROBLEM OF GLIDING

Tendons will not glide through cicatrix or poorly nourished tissues. Our first prob-

lem, therefore, is to excise the surface cicatrix and to replace it with skin and subcutaneous tissue of good quality by means of the pedicle graft. At the same cial Any cicatrix left in place will, of course, heal with cicatrix and bind the tendon Thus our first prerequisite is to provide for the tendon a soft bed of healthy

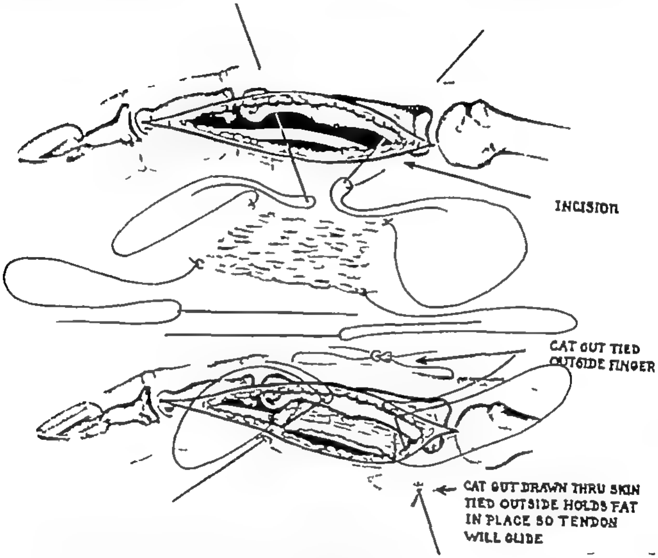


Fig. 320 After freeing a tendon from bone or scar reattachment is lessened if a thin layer of slippery deep fascia or specialized paratenon is interposed.

Drawing shows an easy method of placing such a filmy graft. The No 000 catgut is passed out through the skin and tied to itself on the outside of the finger

time the surrounding skin around the com plete wound margin should be undercut from the deep fascia, allowing it to retract The skin of the full circumference of the limb will then be slack enough to permit good nutrition.

In addition to this we must also excise the deep cicatrix en bloc, to mobilize the parts further, to free the nerves and blood vessels for better nutrition, and to furnish for the tendons a bed which is not cicatri tissue, preferably of fat and especially of the paratenon variety

If a tendon attached by light adhesions is freed and motion is commenced early, the tendon will remain mobile. If, however a tendon is released from cicatrix until it moves freely and is then dropped back into its cicatricial bed it will, of course, again adhere and in two weeks will be as immobile as ever After freeing a tendon from cicatrix, if the cicatrix cannot all be ex

the tendon *may form. Delicate handling* of the tissues by atraumatic technic, as described in Chapter 4 is compulsory in the vicinity of tendons Rough handling of the tissues or marring of the epitenon is surely followed by tissue reaction which ends in adhesions Postoperative oozing of tissues or hematoma formation similarly prevents gliding

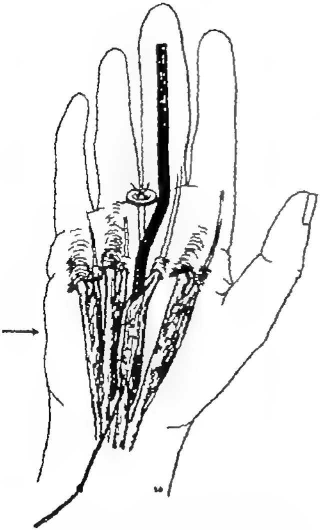


FIG. 322 Protecting in the base of the palm the proximal juncture of a tendon graft (black) from adhesions by wrapping the juncture (indicated by arrow) with the lumbrical muscle. This muscle is normally attached to the profundus tendon which is here being prolonged by a tendon graft into the finger The distal juncture at the distal phalanx does not have to glide.

In general in our tendon repairs we should aim to have *a minimum of moving* parts, but a maximum of gliding material *It is far better* to let one branched tendon do the work of several and to have ample room for gliding than to attempt to reproduce the normal number of tendons packed closely in a cicatricial channel, where they will adhere to each other and to their surroundings and act as one immobile tendon

METHOD OF MAKING AN ARTIFICIAL TENDON SHEATH

To Leo Mayer and later Thatcher is due the credit of experimenting in this field The former used a celluloid tube and the latter one of stainless steel for implantation into the finger so Nature would form about it a synovial lined sheath. Microscopically, such a sheath was actually demonstrated. Straight rods were used, which did not conform to the natural undulating course of the tendon in the finger and, therefore, disregarded the annular sheaths or pulleys. A flat piece of ribbon like stainless steel 7 mm. wide to fit through the pulleys would have obviated this difficulty At the end of three weeks the rod was withdrawn and a tendon graft placed through the channel There was tendency for the tendon juncture in the *distal part of the palm, due to* the presence of the end of the rod and to the two operations, to become adherent. This method is still experimental Mayer has obtained flexion in a finger, but with the *tendons bow-stringing subcutaneously* The results are at this time apparently inconclusive. The principle of producing a synovial lined sheath may still have *its* applications. Possibly these will be limited to laying a flat, thin sheet or foil of stainless steel temporarily between a tendon and cicatricial tissue so as to establish a *synovial lined* cleavage.

Since this was published, J E Milgrim (1945) has been inserting such ribbons in hand about forearm and lower leg, making them about ten times wider than the tendon and suturing the tendon within this artificial sheath He claims that the metal

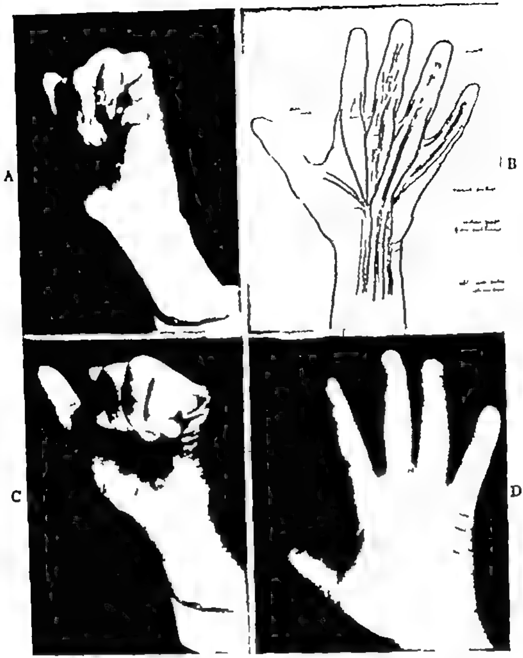


FIG. 323 Case H R. Four months previously he fell, lacerating his palm with a broken bottle, severing the flexor sublimis of the long finger both flexors of the ring finger and the nerves to the third and fourth clefts. Infection followed with sloughing of tendons of the ring finger Tendon of little finger became adherent. Degree of flexion when coming for repair is shown in (A) Hand is anesthetic distal to the palmar scar and including the radial half of the little finger volar surface of the ring finger and ulnar half of the long finger

Operation. Structures of the palm were dissected free from scar tissue. The severed branches of the median and ulnar nerves had a separation of one half inch between their ends. The ends were trimmed off to good nerve fibers and by flexing the fingers were sutured with fine blood-vessel silk perineurally Ends of the sublimis tendon of the long finger which were separated an inch were sutured. There was a gap between the ends of the profundus tendon of the ring finger and its sublimis tendon had withdrawn up the forearm. One and a half inches of the sublimus tendon were used as a free graft to bridge the gap in the profundus tendon. See diagram (B) In three months sensation returned to as far as the middle creases of the fingers and in five months over the complete area. At the sixth month there was some paresthesia which was almost gone at the eighth month, at which time stereognostic sense commenced to return. Perfect function of the tendons returned as shown in (C) and (D) (Courtesy Surg., Gynec., and Obstet., 39.271 Sept., 1924)

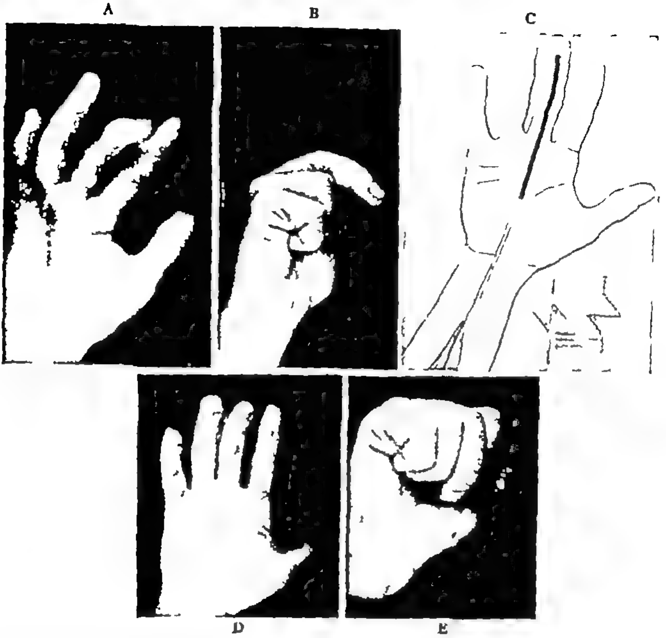


Fig. 324 Case J D T Fourteen months previously the long finger was caught between two wrenches. A severe tenosynovitis followed with middle palmar space infection resulting in adherent flexor tendons and a contracture of the long finger The finger had been further damaged by an operation in which the ill-advised median longitudinal incision was used and a tendon-lengthening operation was done within the finger by splitting it diagonally and resuturing. This merely added more scar tissue in the finger In (A) and (B) are seen limits of *extension and flexion in the finger when coming for repair and the usual result of the median* longitudinal incision.

Operation The scar contracture along the finger was excised and the incision was fashioned into a zigzag line to relieve tension. The damaged flexor tendons were removed from the finger entirely and in their place, sutured to the profundus tendon in the palm, a free graft of the sublimis tendon was substituted. The sublimis muscle was sutured to the profundus for added strength. See diagram (C) In (D) and (E) is shown the resulting function. (Courtesy Surg., Gynec., and Obstet., 39.267 Sept., 1924)

should be removed within three weeks to prevent excessive cicatrix about it. D C McKeever used a special cellophane (#300 PUT 71 DuPont) which he claims is non irritating to intervene between tendon and scar and to separate the bones in arthroplasty He states that the cellophane fragments and collects in wads but that good cleavage is established. Both these methods are encouraging. Farmer determined

that if cellophane is wrapped around the tendon the result is not so good

Polythene, placed under or around tendons so that it is removable, effectively prevents adhesions and is nonirritating Gonzales and Entin showed that a tube of it placed around a tendon or a tendon graft almost doubled the time of healing Polythene sheath is available in any thickness

FREE TENDON GRAFTS

Reasons for Grafting In secondary repair of tendons it is usually necessary to resort to free grafting instead of to direct tendon suture, because it is rarely possible to draw the parted ends of the tendon together for suture without doing so under too great tension It is only after a clean severance of a tendon, and within two months of the accident, that the tendon ends can be drawn together and sutured The reasons for this are the following

After two months, with few exceptions, the muscle becomes fixedly contracted After severance of a tendon each end is usually damaged for at least one-half an

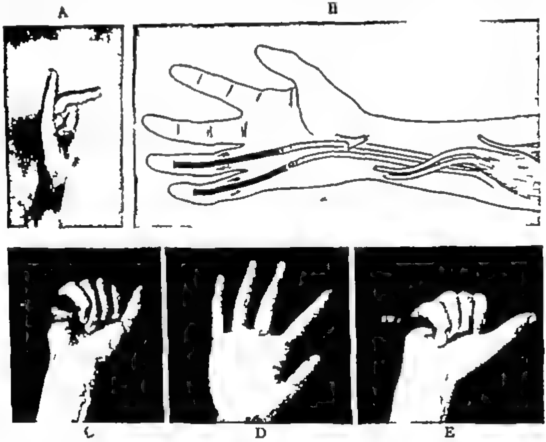


FIG. 325 Case M. D C. Three months previously, a knife severed the flexor tendons of the ring and little fingers over the middle of the proximal phalanges. In (A) is shown the limit of voluntary flexion in these two fingers.

Operation All of the flexor tendons were removed from the ring and little fingers. It was found that much of the tendon sheaths of each finger had been destroyed. As substitutes, free tendon grafts plus paratenon fat were used. In the ring finger a sleeve of paratenon fat taken from the forearm was sutured in place and the sublimis tendon of this finger was cut off high in the forearm drawn through this paratenon sleeve, and used as a free graft to bridge the deficiency in the profundus tendon. In the little finger the tendon of the palmaris longus plus its paratenon was used to supply the defect in the profundus tendon. Its sublimis tendon was cut off All tendon suturing was done in the palm and in distal ends of the fingers, as shown in (B)

(C) (D) and (E) taken three years later show practically normal function restored to hand. (Courtesy Surg., Gynec., and Obstet., 35 95 July 1922)

inch back, so that some tendon length must be sacrificed. After a tendon has been nonfunctioning for several months, the degeneration of disuse sets in and renders it unfit for repair This applies especially to the distal end of a tendon and to the curled-up proximal end, but not to a tendon which has reattached and been under intermittent tension Where a tendon is found to be quite rough and adherent, rather than attempt to repair it and have it readhere it is better to excise it completely and substitute in its place a normal tendon graft free from the effects of trauma or infection Slippery epitenon is always transplanted with a graft, but where the bed is too cicatricial paratenon fat should accompany the tendon as a gliding assembly or should be placed about it later

Fate of Tendon Grafts A free tendon graft receives its nourishment at first from the surrounding lymph and tissue juices until it finally becomes vascularized. Its surface, therefore, lives as such, but in the center of the tendon there occur patches of necrosis, most apparent at the end of the first week. Growing cells in tendons can be seen in grafts after 11 days and eventually these patches of necrosis are substituted by regular tendon cells and fibers During the first two or three weeks the tendon graft is considerably swollen and is surrounded by vascular tissue. Its repair lags behind the repair of a normal tendon by only about a week, so that after a month a tendon graft is fairly strong and by the end of five weeks the danger of breaking is over Even at three weeks, when cells are still actively proliferating in these grafts there is enough strength for guarded exercise During the stage of swelling the appearance of the graft is somewhat pink and translucent, but eventually it contracts to normal size, takes on a pearly sheen and can scarcely be distinguished from normal tendon Microscopically it is the same as normal tendon

Only tendons of moderate size such as those in the forearm, can be grafted, because the larger tendons are so thick that much of their centers must undergo necrosis and substitution by tendon cells This often results in prolonged seepage from the wound until final replacement and healing occur A tubular graft of fascia lata to repair an Achilles tendon acts similarly because the inner surface of the tube does not become nourished Therefore, in grafting large tendons, it is best to use a flat piece of thick fascia lata and to refrain from tubularizing it, in order to give it nourishment through each surface.

In placing tendon grafts it is well to make them slightly longer than they normally should be because in healing there is some tendency to contract. Tendon grafts which become infected usually slough out though occasionally they live through a mild infection Tendon grafts live permanently and will hypertrophy to fulfill the demand put upon them After having placed as many as 1058 free tendon grafts I no longer have any hesitation in using them It is immaterial whether or not the outside lives and the center undergoes creeping substitution because from a practical standpoint these grafts are successful and function in every way like tendons.

Sources of Tendon Grafts The easiest available tendon graft is that of the palmaris longus. Calling it a "spare' removes from the patient any objection to its use. It is five or six inches long, varies in thickness, and is present in large enough size to use in about 80 per cent of cases. Its presence is shown by opposing the thumb or better by flexing the wrist against resistance After exposing the tendon at each end through a one-fourth inch transverse cut in the skin, it can readily be withdrawn from its bed if drawn distalward It can be drawn out proximalward, but less readily The tendon will then have about it a moderate amount of slipping material. If paratenon is desired with the tendon, it is necessary to make the long longitudinal in-

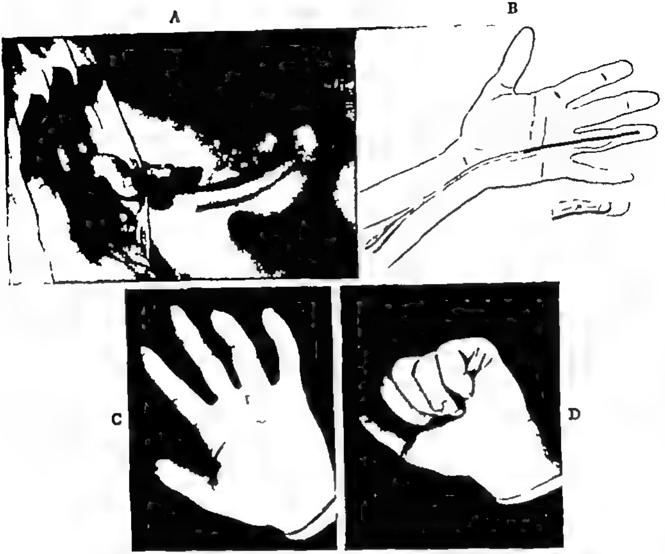


FIG. 326. Case C. J J An infection five months previously in the sheath of the flexor tendons of the ring finger which was drained through a median longitudinal incision in the base of the finger resulted in loss of the flexor tendons and in the scar contracture of the finger which limits the extension, as shown in (A)

Operation. The scar was removed from the volar surface of the finger together with the remains of the flexor tendons, the finger was straightened on a splint and the denuded area was covered by a skin graft from the tubular pedicle in the pectoral region shown in (A) Four months after good skin was supplied, a new flexor tendon was transplanted into the finger from the flexor sublimis of the same digit which was removed from the forearm In the palm it was sutured to the tendon of the flexor profundus, and distally it was fastened through a drillhole in the distal phalanx to the insertion of the extensor tendon, as shown in (B) (C) and (D) taken three months later show the result. (Courtesy Surg., Gynec. and Obstet., 39 267 Sept. 1924)

cision just as it is in removing tendon plus paratenon from the dorsum of the foot. This method gives the best result in movement

In placing a new tendon in a finger a tendon graft often used is that of the flexor sublimis. It is made to prolong the tendon of the flexor profundus from the base of the palm to its insertion to the distal phalanx. The flexor sublimis tendon can be withdrawn through a short transverse incision on the ulnovolar aspect of the forearm two and one half inches above the wrist. The sublimis tendons do not interdigitate as do the profundus and, therefore, can be withdrawn without resistance In some cases these tendons are muscled a little lower than in others. Frequently, in the hand being repaired one or more digits have

been amputated This leaves available for tendon grafts both the flexor and extensor tendons of these digits.

The flexor sublimis and profundus tendons, between the distal crease in the palm and the middle crease in the finger, should never be repaired in the same finger, as they will adhere to each other This rule leaves us free to use the sublimis as a graft.

One or two long extensor tendons can be taken from the dorsum of the hand and forearm for grafting, providing the distal stumps are joined if necessary to the adjacent tendons, so the loss will not be noticed.

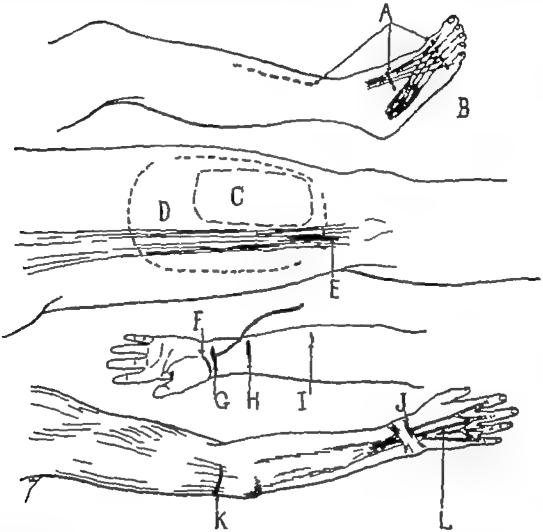


FIG. 327 Sources of grafts with incisions through which they may be reached and for other purposes.

(A) Extensor digitorum communis of the four small toes may be removed through the three incisions (dotted)

(B) Extensor brevis which will continue to provide extension of the toes except the fifth.

(C) Site for obtaining this deep fascia for a gliding surface to place under tendons.

(D) Dotted outline of site of a thin layer of paratenon directly overlying the deep fascia used as gliding material for tendons. A smaller piece is over the outer upper part of the forearm.

(E) Incision for obtaining with a fascial stripper a ribbon of fascia lata as indicated.

(F) Incision for approach to the tuberosity of the scaphoid.

(G) Incision for approach to the lunate

(H) Transverse incision through which the tendons of the flexor sublimis are withdrawn for grafts.

(I and G) Two short incisions for removal of the tendon of the palmaris longus.

(J) Incision for approach to the dorsal end of the scaphoid to place a bone-graft peg

(K) Incision for obtaining the layer of paratenon for gliding overlying the triceps tendon.

(L) An extensor communis tendon may be spared for a graft. The juncturae tendinum will extend the finger

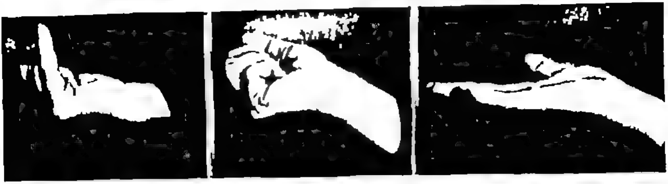


FIG. 328 Case E. \ A spike of glass severed both flexor tendons and the nerve to the radial side of the base of the little finger Wound healed without drainage.

(*Left*) There is no ability to flex the distal two joints. The intrinsic muscles flex the proximal joint. The radial side is anesthetic.

Three weeks from the accident the small nerve was sutured. The flexor profundus tendon was not sutured in the proximal pulley where it might adhere. Instead, a free graft from the flexor sublimis was used, removing the old tendon and suturing the graft to the distal phalanx and to the profundus in the palm.

(*Center* and *Right*) Showing the amount of flexion regained. Sensation returned in two months.

The grafts are obtained through one small transverse incision in the middle of the dorsum of the hand just proximal to the tendon interdigitation and another in the forearm two and one-half inches above the wrist. By pulling on the tendon to the long or ring finger, one ascertains which tendon moves both fingers. The other tendon may then be removed without disability

If it be the little or the index finger that needs a graft, one may instead transfer the flexor sublimis tendon of the next finger, which is longer, to act as a flexor profundus for the shorter finger Recurvatum will occur in the donor finger unless enough sublimis stub at least on one side, is left to prevent it.

In extensive tendon repairs in hands where a full set of tendons are to be supplied we usually need to use the long extensor tendons of the toes. Fortunately, these tendons are not missed, providing we spare the tendons of the extensor digitorum brevis which will continue to extend the toes. From this source by splitting up the main tendon we can obtain for grafting four tendons each a foot long, or one tendon with four tails. The long extensor tendon of the great toe, because of its useful function, is usually not taken It happens that the extensor digitorum brevis tendon is missing for the little toe. This is because in various species of mammalia this tendon is furnished from a slip off what corresponds to our peroneus tertius, instead of the extensor digitorum brevis Therefore, when we rob the little toe of its long extensor tendon we should imbed its distal stump into the adjoining short extensor tendon of the fourth toe, so the little toe will still extend. To obtain the long extensor tendons of the toes one first severs each of these tendons at the bases of the toes through a transverse incision, sparing each tendon of the brevis. Through a short transverse incision high on the dorsum of the foot these tendons are freed from their paratenon by running a tendon stripper down them from above, thus allowing the tendons to be drawn out through this upper incision. Another incision is made longitudinally in the lower leg just external to the tibialis anticus. On then picking up the tendons of the extensor digitorum communis it will be found impossible to withdraw them from the foot, because they branch to the peroneus tertius tendon. Therefore, with a probe, a strong strand of catgut is passed up the tendon sheath. Its lower end is looped about the tendons in the foot which are readily drawn up backward and out through the incision in the

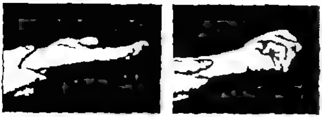


FIG. 329 Case F P Four months previously the base of the left ring finger had been badly lacerated and crushed between a rope and a pulley severing the tendons. There followed primary repair and infection, leaving conditions poor for repair

The ends of the flexor tendons could be felt in the palm. The finger lacked 3¼ inches of voluntarily flexing to the distal crease in the palm and ½ inch passively There was no voluntary flexion in its distal two joints.

At operation the tendons ended in dense scar in the distal or septal part of the palm. The cicatrix was removed and after removing the flexor tendons from the finger a new tendon was supplied by using the flexor sublimis tendon as a graft, suturing at the base of the palm and distal phalanx with removable stainless-steel wire. The illustrations, taken 10 months later show range of motion obtained. In voluntary flexion the finger lacked one inch of touching the distal crease in the palm and ½ inch passively The distal joint had 20 of voluntary motion.

lower leg, stripping off the tendon of the peroneus tertius

If grafts are still needed from another source, the plantaris tendon may be available or one can use strips of fascia lata or of triceps tendon with or without a thin encirclement of paratenon tissue With the conventional pipe like fascia stripper one can obtain a long strip of fascia lata through one small incision above the knee. Fascial strips for tendon grafts are satisfactory in the volar or dorsal aspect of the forearm, but due to their raw edges, which have a tendency to proliferate and attach they are not so suitable for use in the digits.

Preserved Tendon or Fascial Grafts. Much has been written on the use of homografts of fascia or of tendon preserved in alcohol or other chemical and experiments have shown that the eventual result is a tendon that looks fairly like the normal tendon, both in the gross and microscopically The preserved graft does not live as such, but in the course of a month and a half becomes, by the process of creeping substitution, replaced by live tendon tissue. The result is not nearly so satisfactory as that obtained from a live autograft. It becomes more adherent its appearance is yellowish, there is more foreign-body reaction about it, and it stains more like fixed tissue. For these reasons, and because the fewer adhesions we obtain the better, I have refrained from using them in the hand

TENDON TRANSFERS

General Principles In this the tendon or insertion of a healthy muscle is transferred or transplanted to either a bone or an adjoining tendon, so that it can do the work of another muscle Thus, when one group of muscles is paralyzed and the opposing group is pulling the limb into the opposite deformity, by transferring a portion of the latter or other available muscle into the former, there is restored not only a better balance of the opposing muscles but also function substituted for the paralyzed one.

As a basis, let us consider a little of the anatomy and mechanics There are 7 wrist movers, 18 digit movers, and 20 intrinsic muscles. Muscles that move or stabilize the wrist are 2 extensor carpi radiali, flexor carpi radialis palmaris longus, 2 ulnari and the abductor pollicis longus. All are inserted to the metacarpals, the carpus being passive Of the long digit movers 9 extend, 6 for the fingers and 3 for the thumb, and 9 flex, 8 for the fingers and 1 for the thumb Of the intrinsic muscles the 5 thenars move the base of the thumb 4 hypothenars move the base of the little fingers and 11 lumbricals and interossei flex the fingers in their proximal joints, extend them in their distal two and furnish lateral motion.

The bones are expanded on each side of each joint, the expansion on the proximal

side being to give the tendon a better angle of approach and that on the distal side for better leverage

The main problem in the lower extremity in cases of paralysis is to furnish stabilization and for this arthrodeses are primary

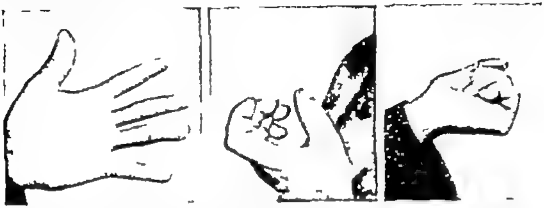


FIG. 330 Case D B (*Left*) The flexor tendons of the index, long and ring fingers were cut across at the middle phalanges. The distal joints hyperextended so that the fingers were useless to him in his sheet metal work. Operation one month later consisted in uniting the severed ends of the tendons, using tendon clamps, and lateral incisions, and planting a sleeve of free fat about each sutured tendon. Photographs show degree of voluntary extension and flexion of the distal interphalangeal joints.

(*Center*) Showing good voluntary flexion in each distal interphalangeal joint after the repair of the flexor tendons in the first three fingers

(*Right*) Showing normal amount of flexion obtained in the repaired fingers. (Courtesy Surg., Gynec., and Obstet., 26 108 Jan. 1918)

and tendon transplantations secondary In the upper extremity, however, restoration of motion by tendon transfer is paramount, but we must not omit furnishing stabilization, either by tendon transfer or by arthrodesis to the joints proximal to the hand Unless there is control through the shoulder elbow and wrist the digits can not function.

Assuming that there is shoulder and elbow control, gripping is possible only when the wrist is stabilized in extension by tendon action or arthrodesis. For proper pinching by the thumb its carpometacarpal joint must be stabilized in extension and its proximal joint in flexion For extension of the fingers there must be stabilizing action at their bases These considerations are essential in planning for muscle coordination and muscle balance in the hand.

Normally when all the muscles are in balance, the hand assumes the position of function For this the wrist is the key joint If flexed, the position of nonfunction is assumed Similarly, in fingers the proximal is the key joint If extended, the fingers tend to assume the intrinsic minus position and if flexed, the intrinsic plus position

Our tendon transfers should be so chosen and adjusted that when the hand and the digits are in the position of function, the muscles will be in balance. There must be stabilizers of the wrist to maintain flexion and dorsiflexion so the digits can work. To demonstrate this one may but place one's finger over the insertions of the wrist movers. When a fist is made, one feels the wrist extensors tighten, and when the digits are extended one feels the wrist flexors tighten Finer adjustments are made, if possible to provide for the normal co-ordination and synchronization of the muscles

In transferring tendons the following principles are essential

1 Our first prerequisite is to correct the deformity We cannot accomplish this merely by transferring a tendon, but must resort first to reshaping the bones and

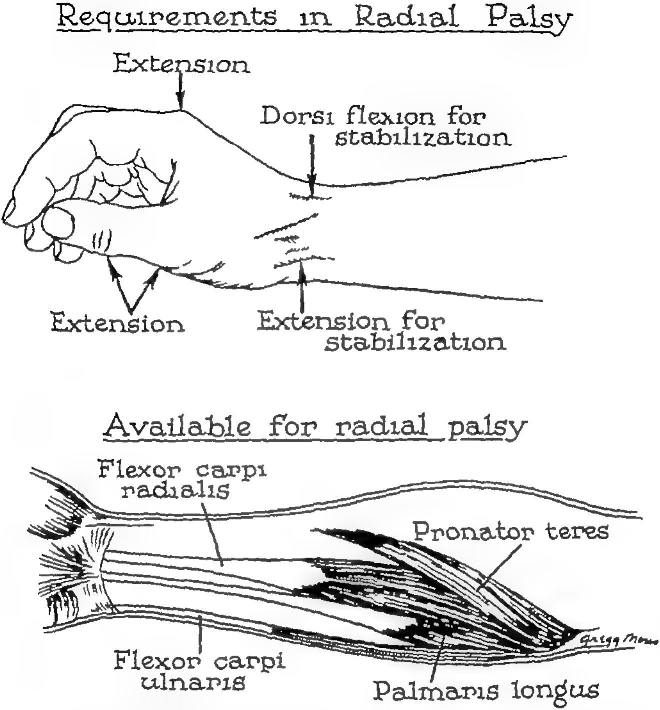


FIG. 330A. For tendon transfers for radial palsy upper diagram shows the four necessities and the lower the four muscles which are available for transfer

joints by osteotomies, capsulotomies, muscle stripping, correcting flexion contractures, etc., until the limb assumes the desired position without resistance.

2 The muscle of the transferred tendon *must be red, healthy and adequate in size* to carry on the muscle balance and the new motion desired otherwise the deformity will recur. Occasionally by furnishing additional leverage the weak muscle may be aided.

3 The transferred tendon should be placed in a bed through which it can glide. If it passes through a hole in fascia, through muscle, or over bare bone, it will adhere. Occasionally, a flap of deep fascia *may be turned under the tendon* to present a smooth surface over which the transferred tendon can glide, or such a piece may be grafted from elsewhere. Junctures should not be made in a carpal tunnel as they adhere.

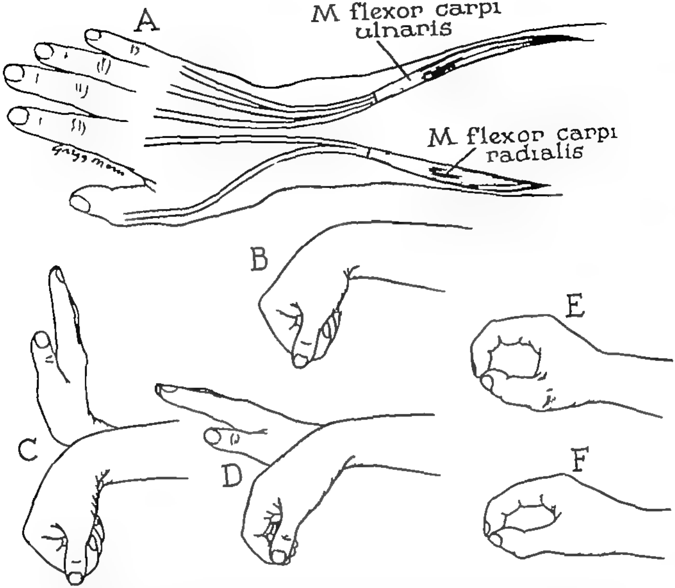


FIG 330B (A) Shows simplest tendon transfer for radial palsy B D and E show the fallacies.
(B) On making a fist the wrist flexes unless a tendon is provided to dorsiflex the wrist.
(C and D) Normal range of motion of wrist and digits and the range gained by transferring wrist movers with their limited excursion to move the digits which require a longer range of excursion.
(E) Normal pinch in form of a circle.
(F) Poor pinch is shape of ellipse unless the stabilizing action of the abductor pollicis longus is furnished.

4 The transferred tendon should, wherever possible, pull in a straight line, or much of its strength or efficiency will be lost. Where a pulley is used the muscle should be sufficiently strong to compensate for the friction

5 The amplitude of motion of the transferred tendon should be sufficient to execute the motion desired We should avoid attaching the transferred tendon to two tendons of different amplitudes of motion. Thus, a transferred tendon should not be attached to both the extensor pollicis longus and the abductor pollicis longus, because the amplitude of the former is twice that of the latter In tendon transfers we cannot hope to be exact in amplitude, but for a rough guide above the wrist the extensors of the digits move 2 inches, the flexors 2⅞ inches, and the wrist tendons 1¼ inches Tension should be so adjusted that the available limited amplitude of excursion is in the best functioning range

6 It is preferable in the upper extremity, though not at all essential, that the transferred muscle have an allied function A

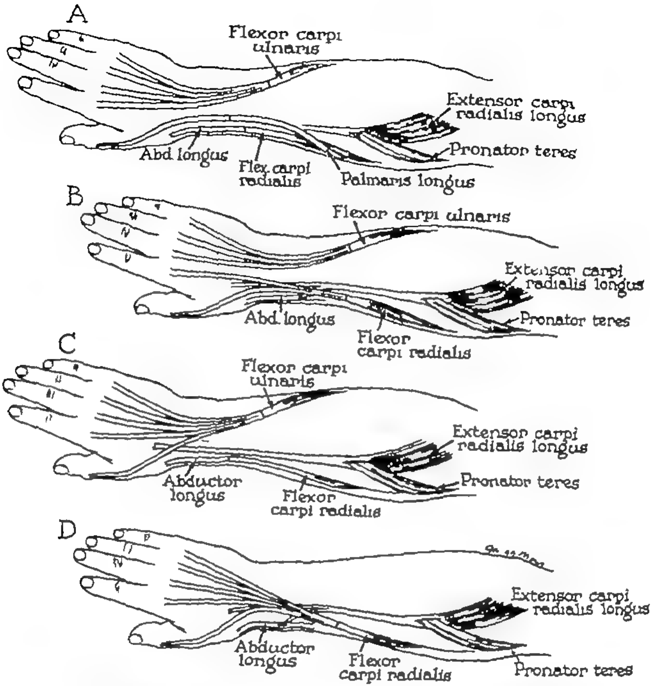


FIG. 330C Methods of tendon transfer for radial palsy all of which give good results. Provision is made for stabilizing wrist in dorsiflexion and metacarpotrapezial joint in extension.

single muscle should not be split up to give two functions The brain will soon adapt itself to the ordinary transfer in the hand and forearm such as using flexors for extensors or vice versa though there is a limit in adaptability Some patients need training Most at first tense the whole limb to execute a movement, but later the motion becomes natural

Tendon transfer should not be planned empirically, but on the general principles. Extensive cases so differ that the plan should be individual. After first deciding what is needed, we should determine what muscles are available

In transferring tendons in the forearm from the flexor to the extensor group or vice versa, there are in general at least three tendons needed to furnish extension to the wrist fingers, and thumb, and three to furnish flexion to fingers and thumb and opposition to the thumb The available muscles

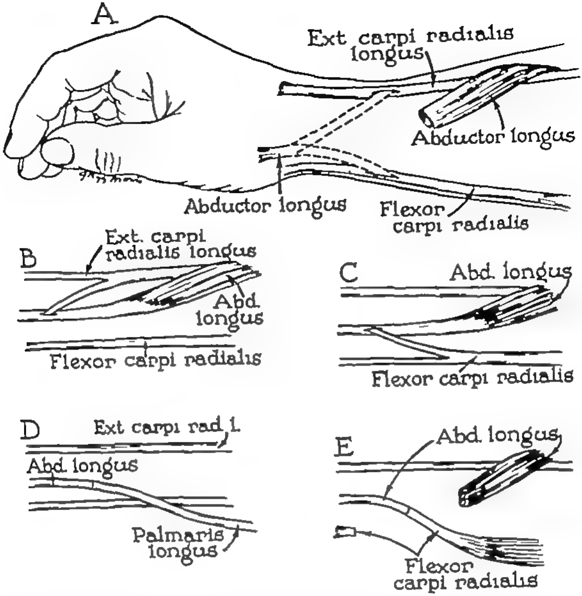


FIG. 330D Methods of activating the abductor pollicis longus to stabilize the metacarpo-trapezial joint in extension for a proper pinch between the thumb and the index finger. When the tendon of the abductor pollicis longus is liberated by slitting its tunnel over the radial styloid the transferred flexors, palmaris longus or flexor carpi radialis retain their action of flexing the wrist

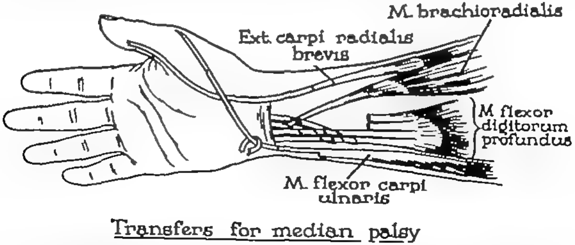


FIG. 330E. Tendon transfers for median palsy. Flexor ulnaris furnishes opposition to the thumb. Flexor digitorum profundus supplied by the ulnar nerve is made to activate all the profundi and is reinforced by the supinator longus. The extensor carpi radialis brevis is transferred to the long flexor of the thumb.

in the extensor group are the extensor carpi radialis longus and brevis, the extensor carpi ulnaris and the supinator longus Those available in the volar aspect are the flexor carpi radialis, the flexor carpi ulnaris, the palmaris longus, and the pronator teres.

It is best for a tendon to be used for one function, though in cases where the functions are similar and the excursions the same a slip from one tendon may be branched off to activate the other tendon also For instance, a slip of either the extensor carpi radialis longus or flexor carpi radialis may be used to activate the abductor pollicis longus

In the following tendon transfers the muscle does not lose its function as it still pulls in approximately the same direction Flexor carpi ulnaris for opposition of the thumb palmaris longus, flexor carpi radialis, and extensor carpi radialis to abductor pollicis longus, and pronator teres to extensors of the wrist.

In planning tendon transfers two procedures arthrodesis and tenodesis, should always be considered as adjuncts or alternatives.

Arthrodesis is a valuable procedure, both to stabilize proximal joints so the distal ones may be activated by tendons and also to place and hold parts of the hand and wrist in the position of function. Any or several joints may be arthrodesed, the shoulder, elbow, wrist, base of thumb, or any joint of any digit. The use of such is a great aid in planning tendon reconstruction. Joints may be stabilized either by tendon transfer or by arthrodesis

If there should be an insufficient number of muscles available for transfer, the wrist can be arthrodesed in dorsiflexion This results in very little disability and makes the five or six powerful tendons that move the wrist available for use on the digits This procedure is usually necessary if any two of the median, radial, and ulnar nerves are not functioning. Tendons that move the wrist in that they have an excursion of only 1¼ inches compared with the long tendons of the digits which have 2 inches or 2¾ inches, cannot move both wrist and digits completely in flexion and extension If, however, the wrist is arthrodesed, they have ample motion to move digits completely as their excursion is no longer needed to move the wrist. In a hand with extensive paralysis a working rule is to arthrodese enough joints in the limb to place it and the hand in the position of function so as to utilize the few muscles that are present to furnish prehension

Tenodesis is much more valuable in the upper extremity, which is not weight bearing, than in the lower It is a procedure which in some cases may yield more function than will arthrodesis The relative values of arthrodesis and tenodesis should be weighed in each case.

Many paralytics very effectively utilize flexion and extension of the wrist to automatically extend and flex the digits respectively In some extreme cases of paralysis in which the wrist has good flexion and extension this motion may be transmitted to the digits by tenodesing to the forearm bones the tendons that activate the digits. Thus, by automatic motion, when the wrist dorsiflexes the digits flex, and when the wrist flexes the digits extend.

In radial palsy if the extensors of the digits are tenodesed to the radius, activating the wrist flexors, which are present, will extend the digits Also activating the digit flexors as in making a fist will dorsiflex the wrist. In paralysis between C6 and C7, in which only the wrist extensors are present, tenodesis of the flexors of the digits and a tendon for opposition will allow the patient to grasp When necessary tenodesis to the humerus by fascial graft to the tendons to the digits may be utilized to aid in this action (see chapter on Arm) Tenodesis of the extensor aponeurosis on the proximal phalanx lessens clawing and allows the long flexors to better flex the proximal joint of a finger

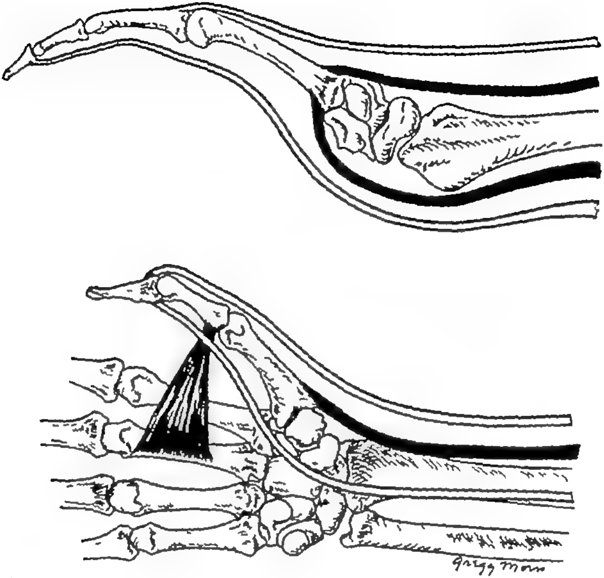


FIG. 330F Principle of stabilization of the proximal joints so the distal joints may be moved.

(*Top*) Wrist movers (*red*) stabilize wrist so digit movers (*blue*) may act.

(*Bottom*) In pinching with thumb, the abductor pollicis longus (*red*) stabilizes the carpometacarpal joint in extension. Also the adductor pollicis (*green*) stabilizes the metacarpophalangeal joint in flexion. These two stabilizers hold the thumb in a firm arch so the digit movers (*blue*) may act.

In transferring tendons for radial palsy all three of the above stabilizers in red should be activated.

For Paralysis of Musculospiral Nerve Above Elbow Here we have wrist drop, thumb and finger drop though the distal two joints of the fingers can be extended by the intrinsic muscles Some supination is furnished by the biceps

With four tendons needed and four flexor muscles available, a good practical result can be obtained What is needed is extension of proximal finger joints and thumb and stabilization in dorsiflexion of the wrist and the base of the thumb (Fig 330A)

Unless the wrist is held firmly in dorsiflexion, either by tendon transfer such as pronator teres to extensor carpi radialis or by arthrodesis, the wrist will draw into flexion on making a fist, and the strength of the grip will be poor

Unless the metacarpal of the thumb is stabilized in extension by tendon transfer or arthrodesis of the trapeziometacarpal joint, the metacarpophalangeal joint will drop, destroying the arch of the thumb and resulting in a weak pinch

There are six methods of transfer to activate the long abductor of the thumb as shown in Fig 330D, using the palmaris longus, the flexor carpi radialis, or a slip from the *extensor carpi radialis which is* being activated by the pronator teres Either flexor or extensor carpi tendons, having allied function and excursion, may be transferred in part or in whole into the abductor pollicis longus

In addition to stabilizing the wrist in dorsiflexion, there should be some tendon left to stabilize it in palmar flexion. Otherwise, if the wrist extensors overact or the wrist flexors underact on attempting to extend the digits the wrist will dorsiflex so greatly that the proximal finger joints can not extend. The patient complains that he cannot push or lift with the palm, or play handball or baseball One wrist flexor, either palmaris longus, flexor carpi ulnaris, or flexor carpi radialis, should be left in place. The palmaris longus is sufficient, if present. If either the palmaris longus or flexor carpi radialis longus can be transferred into the abductor pollicis longus to stabilize the thumb, it may also be used to flex the wrist by merely slitting the annular ligament of the abductor pollicis longus The latter will then bow across and act as a wrist flexor

Junctures of transferred tendons should be made not in a carpal tunnel but proximal to it or they will not glide The flexor carpi radialis and the extensor carpi radialis are too strong to activate the extensor pollicis longus as they will distort.

A natural tenodesis in radial palsy occurs occasionally and works remarkably well The extensors of fingers and thumb have attached to the radius Wrist flexors then extend the digits and digit flexors dorsiflex the wrist When tendons are not available, tenodesis is very satisfactory

Examples of procedures for radial palsy (Fig 330C)

1 Flexor carpi ulnaris to long extensors of long, ring, and little fingers. The lower fibers of this muscle should be freed from the ulna to allow a straight course, and some deep fascia should be turned over under the tendon to furnish a gliding surface A longitudinal incision here facilitates

2 Flexor carpi radialis to the long extensor of the index finger and also the long extensor of the thumb

3 Pronator teres to extensor carpi radialis longus and brevis. Incision is between brachioradialis and extensors of wrist.

4 To the tendon of the abductor pollicis longus can be attached that of the palmaris longus, or else a slip of tendon can be slit up from the now activated extensor carpi radialis longus and transferred to the abductor tendon of the thumb

5 The annular sheath or pulley of the abductor pollicis longus should be slit to furnish flexion of the wrist If for this purpose the palmaris longus is absent, the flexor carpi radialis may be transferred to the abductor pollicis longus, slitting the pulley, and the flexor carpi ulnaris at

tached to the long extensors of all five digits. Another alternative in the absence of the palmaris longus is to arthrodese the wrist. Another good method is to transfer (1) the flexor carpi radialis to the abductor (slitting the pulley), (2) the palmaris longus to extend the thumb, (3) the pronator teres to the extensor carpi radialis longus, and (4) the flexor carpi ulnaris to all finger extensors

A fairly good result can be obtained by simply transferring the flexor ulnaris to the extensors of the last three digits and the flexor carpi radialis to the three extensors of the thumb and index finger This, of course, will not allow the thumb to extend completely, as its long extensor will be held back by the tendon of the long abductor of the thumb which has only half the amplitude of motion. Also, though there will be some ability to dorsiflex the wrist from these transfers the grip will not be strong, as the stabilizing dorsiflexion of the wrist will be weak. (Fig. 330B) If there are not enough tendons available the strong one should be attached to the long extensors of all five digits and the weak one to the abductor of the thumb

From an historical viewpoint Murphy, in 1915, transferred the flexor carpi radialis to all of the extensors of the digits, sparing the flexor carpi ulnaris. Starr in 1922 attached the palmaris longus to all of the thumb extensors and the flexor carpi radialis to the extensors of all the fingers. He spared the flexor carpi ulnaris. Robert Jones in 1922 transferred the flexor carpi radialis to the extensors of the thumb and index finger, the flexor ulnaris to those of the last three fingers, and the pronator teres to the long extensor of the wrist. Zachary in 1947 found that when both flexors were transferred the fingers would not extend in one fifth of the cases because extension was taken up by the wrist, but full extension of the fingers was gained in almost all of the cases when some flexor was left in place. He advised leaving the flexor carpi radialis or the palmaris longus, if present. Luckey suggested when all wrist flexors are transferred to extensors to transfer the sublimis of the ring finger to flex the wrist. In none of the illustrations of any of the above was shown full extension of wrist plus fingers simultaneously nor full flexion of them

Tendon transfer for radial palsy restores practical but not the normal degree of motion It is impossible to extend both wrist and fingers at the same time and to flex them both at the same time as the amplitude of wrist tendons is only one-half that of digit tendons The fingers will extend with the wrist only slightly dorsiflexed, and make a fist only when the wrist is straight or dorsiflexed Only one exception to this have I seen and this patient was double-jointed and unusually flexible. It is, however, possible for the tendons that move the wrist when transferred to the finger tendons to give full motion whether in extension or flexion if the wrist be arthrodesed, as their amplitude of excursion will then be sufficient when they no longer must bend the wrist.

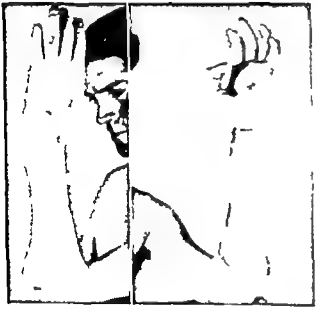
In paralysis of the posterior interosseous nerve alone the extensors of the wrist will be functioning. Therefore, the extensor carpi radialis brevis can be attached to the extensors of the fingers and the long extensor of the thumb and the palmaris longus or a slip off the extensor carpi radialis longus or flexor carpi radialis can be joined to the abductor pollicis longus

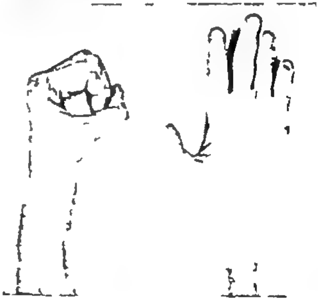
For Paralysis of Median Nerve. Here we need flexion of the fingers flexion of the thumb, and opposition of the thumb The flexor profundus muscle to the ring and little fingers and the flexor ulnaris muscle are functioning. A good combination of transfers is as follows

1 The upper ends of the flexor profundus tendons to the index and long fingers can be detached from their muscles and imbedded into the flexor profundus tendons to the ring and little fingers.

2 The supinator longus muscle can be

FIG. 331 From gunshot wound much of the ulna ulnar nerve and all muscles in the forearm except extensors and flexor of the thumb were blown off (A and B *Top*) After replacing the cicatrix with a large skin flap the wrist was ankylosed in dorsiflexion (C and D *Bottom left*) The extensor carpi radialis longus and brevis were transferred to give useful flexion to thumb and fingers as shown in (E and F *Bottom, right*) (Courtesy of W C. Graham Lt. Col., M C., Valley Forge General Hospital.)





passed over to give additional strength to these four profundus tendons.

3 The tendon of the extensor carpi radialis brevis can be attached to that of the flexor pollicis longus.

4 The flexor or extensor carpi ulnaris tendon can be used to furnish opposition to the thumb (see Chapter 10)

The biceps prolonged by graft has been used to flex the digits. The triceps may be used similarly with less tendency to span the elbow

For Paralysis of Ulnar Nerve. In this the flexor profundus to the ring and little fingers may or may not be partially paralyzed, according to whether the ulnar nerve is severed above or below its branches to them Enough flexion of these will, however, be supplied by the median nerve It is not advisable to join the flexor profundi

of the little and ring fingers to those of the long because this would only increase the deformity due to muscle imbalance for the more the long flexors are working the more marked will be the clawhand. In ulnar paralysis we have loss of action of the hypothenar, two lumbricales, interossei and thumb adductor muscles The tendon prolonged subcutaneously by a sublimis graft to the ulnar side of the proximal phalanx of the thumb To restore muscle balance of the fingers, curvature of the arch and adduction of the thumb see Chapter 10

If the nerves are severed low in the forearm only the transfers for paralysis of the intrinsic muscles will be necessary

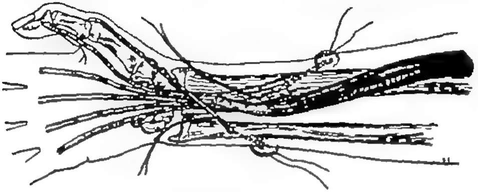


Fig. 332 Tenodeses and tendon transfer for paraplegia at a level between C 6 and C 7 The only motion present in hand is dorsiflexion of the wrist. By acting through tenodeses, this motion is utilized to grasp and to oppose the thumb. The flexor longus pollicis and all the profundus tendons are tenodesed to the radius A grafted sublimis tendon is used by tenodesis one and one half inches up the ulna to oppose the thumb, as in the pulley operation. To furnish in addition some voluntary direct flexion, the brachioradialis tendon is fastened into the flexor tendons below the point of tenodesis.

transfers for this are detailed in Chapter 10 Intrinsic Muscles of the Hand.

For Paralysis of Median and Ulnar Nerves. If severed above the branches to the forearm muscles it is best to ankylose the wrist in about 30° of dorsiflexion thus making available the three extensors of the wrist. The extensor carpi radialis longus can be attached to the profundus tendons for flexion of the fingers and the extensor carpi radialis brevis to the long flexor of the thumb Opposition may then be restored to the thumb by using the supinator longus muscle to act through a long graft of a flexor sublimis tendon, looped around the flexor ulnaris tendon and passed subcutaneously across the thenar eminence to insert on the ulnar side of the base of the proximal phalanx of the thumb As an alternative, the tendon of the extensor carpi ulnaris can be passed around the wrist over a turned-over layer of gliding fascia and

If arthrodesis of the wrist is not desirable, a tenodesis above the wrist can be made of the flexor profundus and flexor pollicis longus tendons The five digits will then flex automatically when the wrist is dorsiflexed. In such a case a fixed opposition of the thumb may be furnished by a bone block or strut procedure between the first two metacarpals or by a pulley operation with tenodesis to the ulna.

For Paralysis of Musculospiral and Ulnar Nerves. 1 Stabilize the wrist in dorsiflexion by arthrodesis.

2 Transfer the flexor carpi radialis to the long extensors of the thumb and index finger

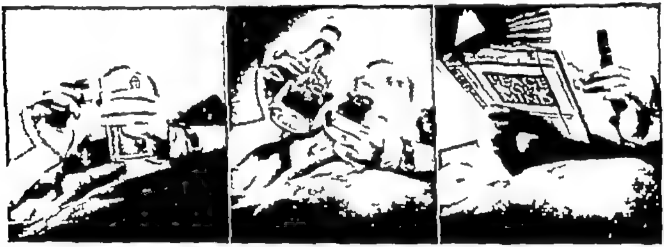
3 Prolong the pronator teres with long tendon graft to extend the long, ring, and little fingers

4 Transfer the palmaris longus tendon to the long abductor of thumb Use the

A B C

FIG. 333 (A, B C, *Top*) Paraplegia between C 6 and C 7 The only active motion of hand is dorsiflexion of the wrist. The patient was unable to hold objects other than by the method shown.

(D E, F *Bottom*) Flexor profundus tendons and long flexor of thumb were tenodesed to radius and by a pulley operation for opposition of the thumb and the grafted sublimis tendon was tenodesed to the ulna 1½ inches above the wrist. Dorsiflexion of the wrist then caused the fingers and thumb to flex and the thumb to oppose. Some voluntary flexion of digits was given by transferring into the flexors below the point of tenodesis the supinator longus. He could then pick up objects help himself and be liberated from complete dependence on nurses. Nursing care was lessened.



D E F

flexor sublimis tendons to restore the action of the intrinsic muscles of the hand.

For Lower Brachial Plexus Palsy Involving T 1 C 8 and part of C 7 Required are opposition of thumb, action of intrinsic muscles of hand, and flexion of thumb and fingers

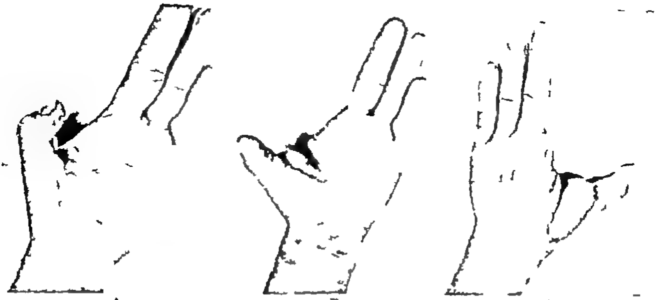
Available are flexor carpi radialis extensor carpi brevis and longus, extensor ulnaris, and supinator longus.

1 Arthrodese the wrist.

2 Transfer the extensor carpi radialis longus about the radial side to the flexor of the thumb

3 Transfer the extensor carpi radialis brevis about the ulnar side to flex the fingers.

4 Transfer the extensor ulnaris, flexor carpi radialis, supinator longus, and tendons of the sublimis to restore opposition and adduction of the thumb and muscle balance in the fingers (see Chapter 10)



A B C

FIG 334 (A, *Top, left*) From the explosion of a 20 mm. shell, this patient lost the index finger and had a flexion contracture of the first cleft with destruction of adductor muscles and ankylosis of the distal thumb joint in excessive flexion. (B and C, *Top, center* and *right*) A thumb cleft was established by removing remains of the second metacarpal and placing a pedicle skin graft, but the thumb could not adduct. The sublimis tendon of the missing finger was threaded through a pulley of tendon made in the palm and fastened to the ulnar side of the first metacarpal.

(D, *Bottom*) The thumb adducts to the hand. (Courtesy of W C. Graham, Lt. Col., M C., Valley Forge General Hospital.)

D

For Deformity of Pronation. This is usually seen in spastic or ischemic cases or those with muscle imbalance combined with flexion of wrist and digits

1 Detach the insertions of the pronator teres and flexor carpi radialis. Implant the former into the latter and transfer the conjoined tendon through the interosseous space to insert in a drill hole in the posterior lower part of the radius (Tubby) This is of doubtful efficiency

2 Do as in No 1, but strip the pronator teres with its nerve supply as high as possible, and transfer the conjoined tendon subcutaneously around the ulnar side to the dorsum of the forearm to insert low on the radius (Mayer)

3 Detach the insertion of the flexor carpi ulnaris, strip it high, and pass it subcutaneously around the dorsum of the forearm to insert low on the radius (Steindler)

4 Sever the pronator quadratus.

5 In extreme cases, if the period of

growth is over, fuse the lower radio-ulnar articulation in supination by bone graft or do a rotary osteotomy on the ulna

For Paralysis of Intrinsic Muscles of Hand, see Chapter 10

For Paraplegia Between C 6 and C 7 The patient is helpless in bed, unable to pick up anything The only action in the hand is dorsiflexion of the wrist. He may be given ability to pick up objects by using the principle of automatic movements. This, to him, means much, and it greatly relieves in nursing care (Figs 332 and 333)

The tendons of the flexor profundus and the flexor of the thumb are securely fastened to the radius with the digits extended but the wrist flexed On extension of the wrist they will automatically flex The tendon of the brachioradialis muscle may be inserted into them lower than their attachment to the radius to supplement the automatic movements with some direct voluntary flexion.

To furnish opposition to the thumb a free tendon graft, from a sublimis or palmaris longus tendon, is used as in the pulley operation and tenodesed to the ulna 1½ inches above the wrist. When the wrist is extended the thumb will oppose. Postoperatively the whole of each arm must be encased in plaster for a month with elbow flexed as well as wrist to protect the brachioradialis.

For Paraplegia Between C 7 and C 8. Here there is loss of flexion of all digits and loss of action of all intrinsic muscles.

1 Transfer extensor carpi brevis to flexor of thumb

2 Transfer flexor carpi radialis to all flexor profundus tendons

3 Transfer flexor carpi ulnaris to give opposition to the thumb

4 Transfer extensor indicis proprius to outer side of the proximal phalanx of the index finger for abduction of the finger

Each case should be studied individually as many do not fall under the above headings, for they may be due to injury or to

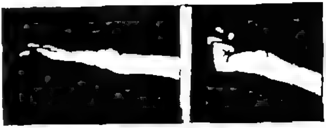


FIG. 335 Case M T, aged 17 Six months previously he tripped and fell, striking his hand on a broken stump lacerating across the base of the little finger severing the flexor tendons He had good flexion of the proximal joint of the finger but no voluntary flexion in either the middle or distal finger joint, the finger inflexion extending straight forward.

At operation the distal ends were recovered at the middle joint and removed, and the proximal ends in the palm. The tendon of the palmaris longus was used as a free graft to prolong the profundus tendon the suturing being in the base of the palm and to the distal phalanx. Also a two-ply pulley over the metacarpal head was constructed of the sublimis tendon. Removable stainless-steel wire was used. Complete range of motion was obtained as shown in the photographs taken two and one half months later

poliomyelitis. Therefore, the above plans are given only as suggestions. When some digits are amputated their muscles and tendons may be used. In each case we must figure what is needed and which muscles are available

Other Tendon Transfers. For the abductor pollicis longus a slip may be slit up and transferred from the tendon of the extensor carpi radialis longus or that of the flexor carpi radialis Both work well, as they have the same amplitude and allied function and still retain some power to extend or flex the wrist respectively

The extensor carpi radialis brevis or the extensor carpi ulnaris may be transferred to the long flexor of the thumb under the carpal ligament or subcutaneously

In a case of ankylosed elbow, Milgrim prolonged the biceps tendon with a graft to those of the flexors of the digits There was much bowing of the tendon at the elbow Part of the triceps was used to extend the digits in this case.

In a case of absence of the triceps function, the presence of biceps and flexor carpi radialis, but absence of all other muscles below the elbow, Luckey after arthrodesing the wrist joined the flexor carpi radialis to the flexors of the digits and by a long fascial graft the extensors of the digits to the humerus The latter extended the digits when gravity extended the elbow

Deformities from Muscle Imbalance. Postural deformities due to unequal pull of the muscles are greatest in spastic cases, in *which the positions are often grotesque.* Even in paralytic cases, however, the deformity may increase with time and growth until it is extreme. Each muscle has its special action. If a muscle is stronger it overpulls the limb around in its own way If it is weaker the other muscles overpull, producing the postural deformity characteristic of the muscle paralyzed. Therefore, each muscle may cause two different deformities, depending on whether it be stronger or weaker than is proper for normal muscle balance.

For intrinsic muscles positions of deformity may be designated as intrinsic plus (accoucheur's hand), or intrinsic minus (clawhand) Plus of the long extensors gives hyperextension of the proximal finger joints, and minus gives a drop hand Plus for flexor profundus gives the position of clenched fist, and for the flexor sublimis flexion of the proximal two joints but extension of the distal one. Whenever a joint proximal in the hand is strongly angulated, *the ones distal to it* go into opposite angulation in response to altered tension of the tendons which are then off balance.

FIG 336 Tendon strippers of graded sizes are useful for freeing tendons from adhesions. The tendon is held taut as shown and the edge of the stripper with a twirling motion, follows down the surface of the tendon like a plane.

Postural deformities are corrected, after first overcoming the flexion contracture, by restoring muscle balance through tendon transfers or tenotomies, and if necessary arthrodesis These are contraindicated in athetosis or ataxia.

For Hemiplegia. To counteract the strong flexion of wrist and fingers, a splint to hold them in opposite direction is worn for a week at a time, often enough to prevent extreme deformity Also, the wrist may be ankylosed in dorsiflexion, the pronator quadratus cut and the tendon transfers for pronation carried out. Some joints of the digits may be ankylosed.

TECHNIC OF REPAIRING TENDONS

Dissection

After every repair of a tendon adhesions *form and limit motion. How can we minimize these adhesions?* We know that when a limb remains swollen, inflammatory, and immobile the joints and tendons become adherent. The more exudate between the tissue cells, the firmer will be the resulting binding By scrupulous asepsis we should avoid even that milder degree of inflammation with edema of exudate but in which no pus is formed. Our technic should also be atraumatic, as tissue reaction to pure trauma is almost as binding to movable parts as is the fibrosis of infection. Binding fibrosis is our arch enemy *so* handling of the tissues should be reduced to a minimum, keeping the delicate *histologic struc*

ture of the tendons and surrounding tissues always in mind Every tiny scratch, bruise, or tear is followed by tissue reaction and binding fibrous exudate. At the completion of the operation our wounds should be dry and volumatous pressure dressings should be so firmly applied that there will be no space for a hematoma to form Tiny rubber tube drains, pressure dressings, splinting, and elevation all lessen the amount of fibrous exudate surrounding our repaired tissues.

In dissecting out adherent and damaged tendons we should start away from the cicatrix and work toward it with feather like strokes of the knife, following down the tendon but with the edge of the blade directed away from it. When visual knife dissection is not practicable, a tendon stripper will free the tendon for from one to several inches wherever the tendon course is not tortuous The tendon is slipped through the slit in the tube end of the stripper and held taut The stripper, with a twirling motion of its sharp steel edge, planes its way down the surface of the tendon, separating it from surrounding adhesions. In removing a tendon from a finger it is usually best to slit the finger the full length midlaterally and to dissect under vision, using the stripper for short distances.

In the forearm and palm great proliferation of paratenon will be encountered, forming bands from tendon to tendon and to the surrounding ligamentous parts. This is best excised Wherever tendons run through cicatrix this scar tissue should also be excised, back to normal tissue if possible, and when the tendon must be dropped back against a bed of scar tissue or raw bone some gliding material should be interposed by swinging a flap or by grafting Frequently when tendons are exposed in the forearm or palm one finds that if the fingers are passively flexed and a firm pull on the tendons is made adhesions within the fingers will give way to the extent that the finger can then be fully flexed by a pull on the tendons. Unless motion is commenced early and persisted in such adhesions will reform.

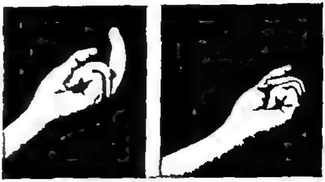


Fig. 337 Case M R. A whirling steel plate lacerated across the juncture of the palm and long finger severing the flexor tendons. A primary tendon repair had been attempted, using the ill advised median longitudinal incision, but the tendons separated later

At secondary operation there was found a great mass of cicatrix in finger and palm. Tendons were removed from the finger and the profundus tendon in the palm was prolonged to the distal phalanx by a tendon graft from the flexor sublimis. A proximal pulley was reconstructed by a graft from the palmaris longus.

(Left) Preoperative limit of flexion.

(Right) Degree of flexion obtained which is fair considering the amount of cicatrix. The distal joint alone had 25 of voluntary motion.

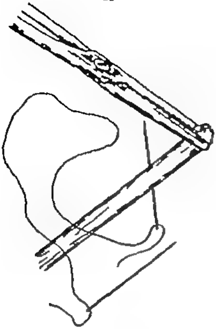
After our tendons are dissected out and the rough and adherent ones excised, a survey is made as to what new tendons are needed, how the gaps between tendon ends can be filled, what tendons are available for grafts, and what muscles for motor power The muscle bundles in the forearm are divided up into the number of motors desired, and by grafting, transferring, etc., the continuity of the tendons is re-established. Our aim should be excision of all surrounding cicatrix to healthy tissue, a minimal number of moving tendons, and a maximal amount of gliding mechanism.

Suturing Technic

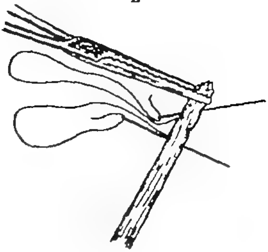
Principle

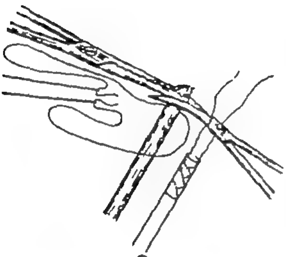
In joining a tendon end to-end by suture our object should be to hold the ends to-

A

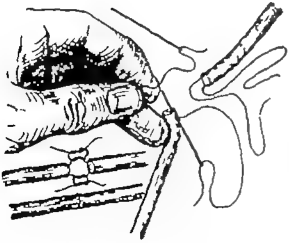


B





C



D

FIG. 338 Showing former method of uniting tendons end-to-end with silk. The delicate epitenon is not traumatized.

As shown in (A), with the tendon held taut by a Kocher hemostat, one of the two needles is passed through it diagonally starting about a centimeter back. Three similar stitches in all are taken with this needle. At each the needle re-enters the tendon a short transverse distance from where it emerged and finally the needle emerges two or three millimeters from the hemostat, but on the opposite side of the tendon from where it first entered.

In (B) is shown the other needle starting its first *stitch transversely across the tendon, entering only a few fibers transversely away from where the first* needle entered (reversed in the diagram) With this needle three diagonal stitches are then taken, just as with the first needle, emerging from the tendon directly opposite where the first needle emerged.

The traumatized cicatricial tip of the tendon is snipped off as in (C) and in the insert the stitch *is shown as it will be when finally placed.*

In (D) while the tendon is held taut over the finger by one suture, the other suture is passed back through the point where it emerged and is made to emerge from the end of the tendon on that same side.

Each suture is then pulled firmly to remove all slack and is tied to the suture opposite it, which emerges from the end of the other tendon, and the result is as shown in insert. (Courtesy Jour Bone and Joint Surg 10 10 1928.)

gether sufficiently firmly until physiologic union occurs After three weeks the latter alone will suffice, the suture material being from then on superfluous. We should reduce our suture material or foreign body to a minimum It is better to have only two strands of strong material than multiple weak strands The stitch should be braided or spliced into a length of tendon to give adequate strength, and not placed in such a way as to strangle the tendon tissue. A core suture is preferable to a surface stitch The latter acts as a foreign body, producing adhesions to the surface of the tendon where they are least wanted. A firm tug should be made on the projecting suture ends, so as to take out all of the slack before the tendon ends are approximated Otherwise, this slack will be worked out later and the tendon ends will separate. The inner part of the tendon in the bite of the stitch will, of course, undergo necrosis. This, however, will be followed by creeping substitution and replaced by good tendon tissue.

Formerly, I spliced my silk in each tendon end so that the two strands emerged from the cut end of the tendon. The slack was then pulled out and the opposing silk strands tied to each other, leaving two knots between the tendon ends. This was quite satisfactory and is still useful in many instances. The knots did not interfere with healing, as there was no trouble from parting of the tendons I later found that the silk, after being first placed in one tendon end and the slack drawn out, could be continued, splicing it up the other tendon end where its slack could also be drawn out. The trick of doing this was merely to pull one strand at a time and slide the tendon end down over this straightened strand, thus snugging the tendon ends together A single knot was then tied, allowing it to sink into the tendon The advantage is one knot instead of two, no knots between the tendon ends, and the knot which is the vulnerable part of the stitch

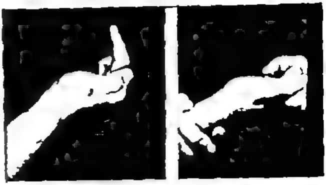


Fig 339 Case J B aged 11
(*Left*) Six weeks previously severed by a glass bottle flexor tendons of index finger opposite the metacarpal head. Sutured tendons with removable stainless-steel wire and sutured volar digital nerve.
(*Right*) Four months later tip lacked only $\frac{3}{8}$ inch of touching distal crease in palm Sensation returned.

placed where it will receive the least strain. Though in the last few years I have been using removable stainless steel wire for tendons, both the silk and the wire technics should be described as each has its place

Silk Technic

The Suture. Silk should be untreated because knots of treated silk slip and untie. For a flexor tendon of a finger, the smallest size should be used that will withstand a three pound pull A knot weakens tensile strength 35 to 40 per cent. In the type of suture recommended the knot is away from the strain and there are two strands to withstand the pull The designation of sizes of the different brands of silk by number is not uniform.

A piece of silk one foot long is threaded at each end with a spear point needle 2½ inches long and .020 of an inch in diameter This needle is made specially for me by Reid Brothers, 316 Mission St., San Francisco, and is excellent for tendon and plastic work. Each tendon end to be joined is grasped at its very tip by a Kocher hemostat and held taut. Commencing five eighths of an inch back, each needle is passed back and forth through the tendon three or four times in opposite directions

progressively down the tendon, and made to emerge from the tendon end. After drawing them taut to remove the slack, the sutures are then similarly passed on up the opposite tendon end and brought out through a single hole about five-eighths of an inch up

Here the needle must not stab the other suture or the tendon will not slip. To avoid it each needle is made to keep to its own half of the tendon or both needles are thrust through simultaneously The tip of each tendon end which was grasped by a hemostat is clipped off. One of the silk strands is now pulled straight and taut, and the second tendon end is slid down over it until it pushes against the first tendon end. Then the second silk strand is drawn straight and taut until it also has slid through the tendon. There is then no more slack to be taken up in the second tendon end and the two strands of silk are tied to each other, sinking the knot into the depth

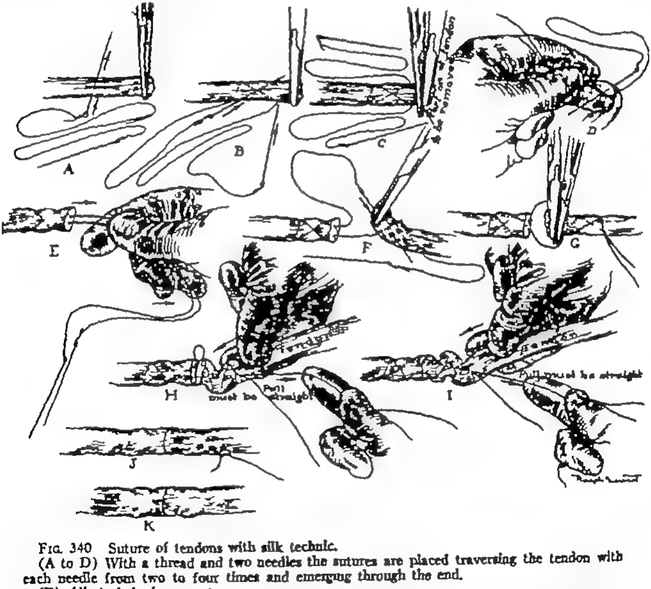


FIG. 340 Suture of tendons with silk technic.

(A to D) With a thread and two needles the sutures are placed traversing the tendon with each needle from two to four times and emerging through the end.

(E) All slack is drawn out.

(F and G) The suture is continued similarly up the other tendon. Both ends are brought out at the same spot. In placing the last strand in the second tendon end the needle must not spear the other thread or they will not slip. By keeping the needles on separate sides of the tendon this is avoided, or better both needles may be thrust through the tendon simultaneously

(H and I) To prevent the tendon ends from separating under strain the slack is removed from the second tendon. To do this one suture is pulled at a time as the tendon is shoved along it to snug against the other tendon end.

(J and K) There is but one knot when tied it sinks into the tendon and at a place where it receives the least strain as knots are the weakest parts of a tendon suture

FIG. 341 Case M. S.
(*Left*) Limitation of flexion of fingers from automobile accident lacerating across palm, fracturing metacarpals and followed by infection.
At operation the tendons were freed from dense adhesions to the metacarpals and a sheet of paratenon fat from over triceps tendon was grafted beneath them The sublimis tendons to long and ring fingers were so rough they were removed from palm and fingers and their proximal ends sutured into the profundus tendon. Two severed nerves were sutured
(*Center* and *Right*) Full range of motion and sensation returned four months later

of the tendon. At a five-pound pull the tendon commences to separate There are many places, where a tendon glides freely enough, where direct tendon suture by silk is useful, such as in the forearm or base of the palm. Also, another material is available, namely, an exceedingly strong fine flexible, twisted stainless steel wire 3 x 08 mm "Fagersta" from Stille Werner, Stockholm. No 36 stainless steel wire as second choice is so fine that it may be used for the tendon suture in the forearm or base of the palm and left in without incurring too much mechanical irritation No 34 wire is too large. The advantage of not using a withdrawable suture proximally in the tendon graft is that a little early motion is possible A very little motion may be a good thing

Placing Grafts. In suturing a tendon graft to a tendon end the same stitch is used, but when the graft is only an inch or two long the graft is merely threaded over the two strands of silk and held so between the tendon ends It may be attached to each tendon end by a fine approximation suture of blood vessel silk but only if necessary To pass the two silk sutures longitudinally through a segment of tendon graft, the graft is held taut at each end by a hemo

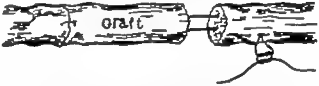


FIG. 342 Bridging a tendon by a short tendon graft, using a silk suture. The silk is fastened to one tendon end, threaded through the graft, while the latter is held taut by two hemostats and then braided through the distal tendon end. To slide the tendon ends together each silk strand is tightened alternately not at the same time. A tiny suture may be used to keep the graft from sliding away from a tendon end.

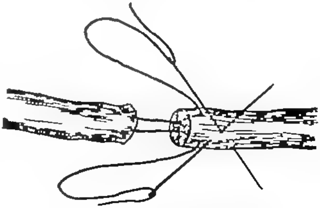


FIG. 343 In suturing tendons with silk, if a needle penetrates a silk strand the tendon cannot be slid down the suture against the other tendon end. To avoid this, both needles are thrust through the second tendon end simultaneously

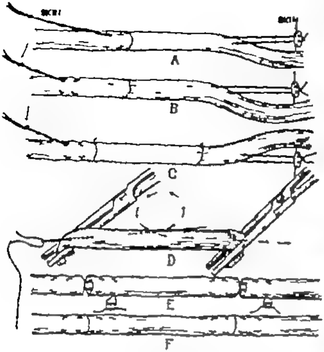


FIG 344 Methods of tendon suture.
(A, B and C) Stainless steel pull-out sutures.
(A) Threading the suture through the distal tendon end holds the tendon ends in good approximation. The pull-out wire is twisted to prevent tissue growing between and hindering withdrawal.
(B) Placing the splicing part of the suture at a distance to lessen adhesions at the important place, the junction.
(C) A short graft may be threaded on the suture wires A tiny stitch of the finest silk keeps each end of the graft opposed to the tendon end.
(D) Method of threading the sutures longitudinally through a tendon
(E and F) Inserting a graft between tendon ends using a silk suture. Short grafts may be threaded on the silk as in (C)

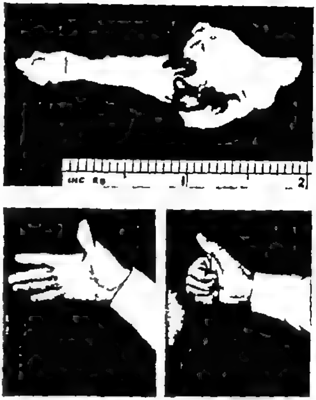


FIG. 345 Silk suture *versus* removable stainless-steel wire suture.
Case A. T Six months previously after laceration on a bottle a primary suture of the severed flexor tendons of the index finger had been done in the proximal segment. It was ascertained that the wound had healed per primam, but he had only a trace of voluntary movement of the middle joint and none in the distal joint. The ulnar side was anesthetic.
(*Top*) Appearance of tendon which had been primarily sutured with silk and healed without infection. The cicatricial reaction bound them solidly in their bed. Tendon ends had separated half an inch. This argues for the use of removable stainless-steel wire.
The tendons and cicatrix were removed, the volar nerve repaired, and a free tendon graft of flexor sublimis was placed with removable stainless-steel wire.
(*Bottom*) Taken two years later showing complete motion. Sensation returned in three months.

stat. The hemostats are then slightly rolled away from each other and the long straight needles are thrust longitudinally through the length of the graft, drawing the silk strands after them. The ends of the graft are then clipped off

Attaching to Distal Phalanx. To attach a flexor tendon to the distal phalanx of the finger by silk, first the anterior surface of the phalanx is scraped with a little chisel for a tendon to-bone attachment Then the base of the phalanx is drilled through from one side to the other by a dental finger drill One of the strands of silk is passed through this hole and is tied to the other strand This holds the ends of *the tendon end snugly against the chiseled* area on the bone. To facilitate passing the silk strand through the drillhole, a curved mosquito hemostat grasps the point of the drill after it has penetrated the bone, the hemostat is relaxed but held in place. After

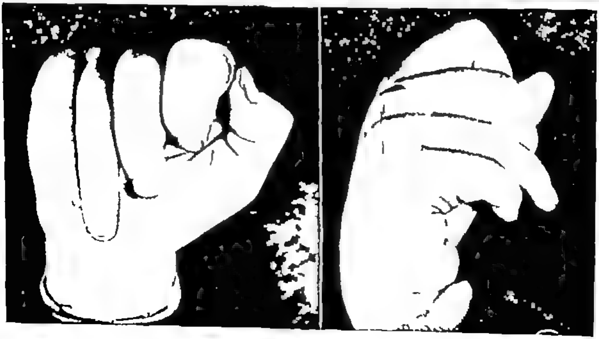
withdrawing the drill a loop of fine wire is passed through the hole in the bone, on closing the hemostat this wire loop is drawn out enough to receive through it one silk strand which is then pulled through For improved methods with stainless steel, see illustrations

Technic of Removable Stainless Steel Wire Tendon Suture

Principle. Suture material acts as a foreign body and provokes about it fibrous, proliferative reaction Stainless steel wire, chosen as the least irritating suture, is smooth and for its strength is much finer than silk. Most metals cause tissue reaction from their electrolytic qualities It is now established, through dentistry and bone surgery, that vitallium, tantalum and 18 8 molybdenum steel remain in tissues with practically no reaction. Vitallium cannot be made into wire, but steel with 18 per cent chromium, 8 per cent nickel, and enough molybdenum to make an even mixture is readily made into wire. A tendon sutured with wire shows less tissue reaction than with silk, which up until now has been the choice for tendon suture. Tantalum is inert in tissues but its tensile strength is low and it does not tie smoothly

When tendons sutured with wire are subjected to constant angulation as they are opposite a wrist or joint, inspection months later will reveal either that the wire has

FIG. 346 Knife wound across proximal segments of last three fingers unfortunately repaired through median longitudinal incisions and not successfully Repaired later by tendon grafts with fairly good function. (Courtesy of L. D Howard, Lt. Col., M.C., Wakeman General Hospital.)



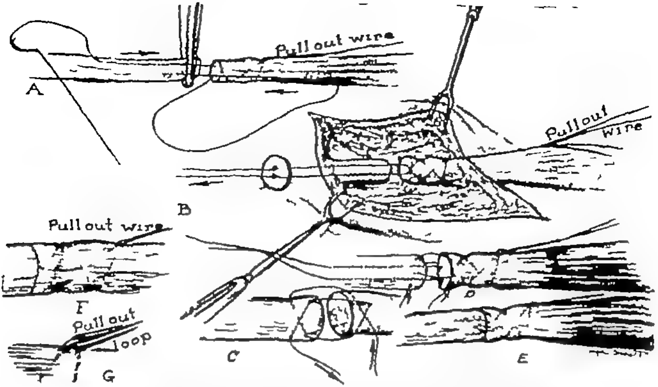


FIG. 347 Suturing a tendon with removable stainless-steel wire which is nonirritating. After three weeks a silk suture has fulfilled its mission and if it remains is merely an irritating foreign body Only one tendon end pulls the other being passive (B) The button on the skin spares the juncture from muscle pull. (B and G) A pull-out wire is brought out through the skin to withdraw the suture in three weeks. Insert C and E shows the double right angle suture of finest silk used merely for approximation and rarely necessary

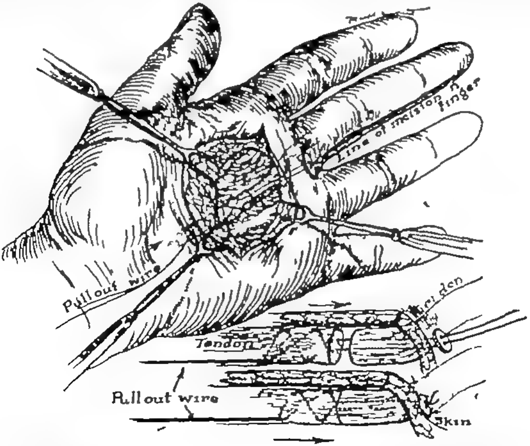


FIG. 348. Suturing a tendon in palm by removable stainless-steel wire. In three weeks the tendon will have joined and the suture after being cut beneath the button may be withdrawn backward by the pull-out wire which is looped about it.

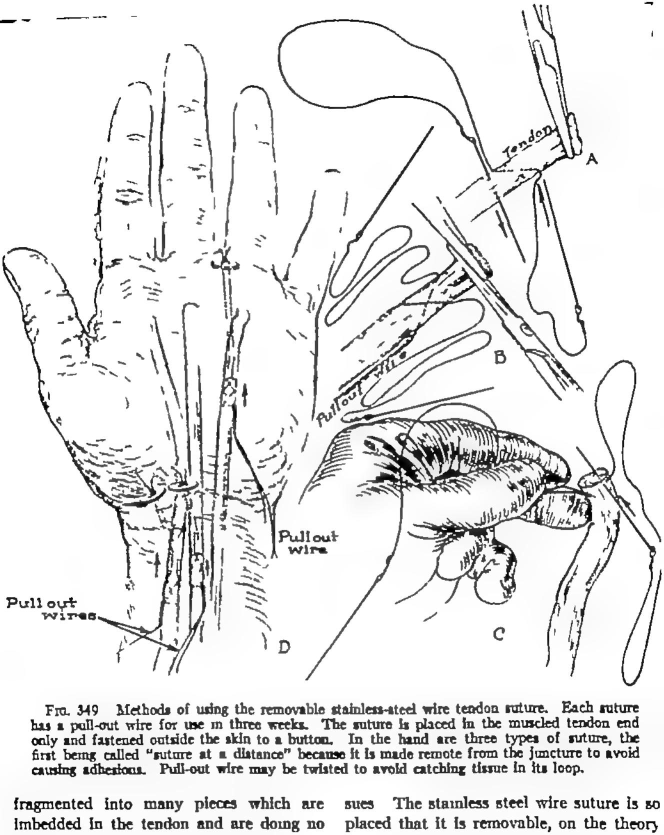


FIG. 349 Methods of using the removable stainless-steel wire tendon suture. Each suture has a pull-out wire for use in three weeks. The suture is placed in the muscled tendon end only and fastened outside the skin to a button. In the hand are three types of suture, the first being called "suture at a distance" because it is made remote from the juncture to avoid causing adhesions. Pull-out wire may be twisted to avoid catching tissue in its loop.

fragmented into many pieces which are imbedded in the tendon and are doing no harm or not fragmented but from the mechanical irritation some tissue reaction may be present in the vicinity of the wire. Any metal, if left in movable tissue, irritates mechanically At insertions and where ten dons pull straight without angulating, the wire suture merely remains inert in the tissues The stainless steel wire suture is so placed that it is removable, on the theory that the absence of any suture leaves the repaired tendon in a better condition to be freer from adhesions than the presence of any suture. The removable feature also eliminates any mechanical irritation. Our suture holds the tendon in place for only three weeks, at which time physiologic

union has taken place and the suture is withdrawn, leaving the tendon juncture free to be as normal as is possible. A silk suture is spliced into the proximal *end only*, is passed on down the limb through the other tendon, and brought out through the

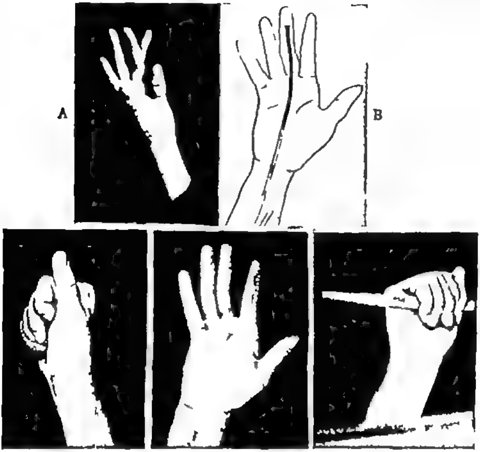


FIG. 350 Case R. K. Four years previously the flexor tendons of the long finger had been severed with a knife over the proximal phalanx, resulting in complete loss of voluntary flexion in the last two joints and most of that in the proximal joint and in the deformity shown in (A)
Operation. Through an incision in the wrist the sublimis and profundus tendons of the long finger were freed with a stripper to the far end of the palm, where they blended to scar tissue and were drawn out of the arm Through an L-shaped incision in the distal crease of the finger the distal end of the profundus tendon was stripped down through the finger until it tapered out. It was withdrawn from the finger and cut off The sublimis tendon was cut off high in the forearm. With the expanded probe a channel was dilated in the finger and the free graft of the sublimis tendon was drawn through and used to bridge the gap in the profundus tendon, as shown in (B) (C, D and E) taken four months later show the amount of function restored to the finger (Courtesy Surg., Gynec., and Obstet., 35 93 July 1922)

suture fulfills its mission in three weeks and after that is just an irritating foreign body

The tension or pull on a tendon suture is from one end only that to which the muscle is attached, the other end of the tendon remaining passive Therefore the wire skin there to be fastened firmly to a button, to adhesive plaster, or to the fingernail The proximal end of the tendon is thus held distalward against the passive distal tendon end. Here, though seldom necessary, a feeble approximation stitch can be placed with the finest of blood-vessel silk

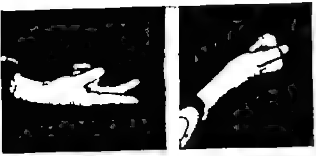


FIG. 351 Case W P aged 11 Two months previously he severed with glass the flexor profundus and half of the sublimis tendons of the index finger at the middle joint. These were repaired by removable stainless-steel wire.

The illustrations show the motion six months later The distal joint tested alone flexed 45

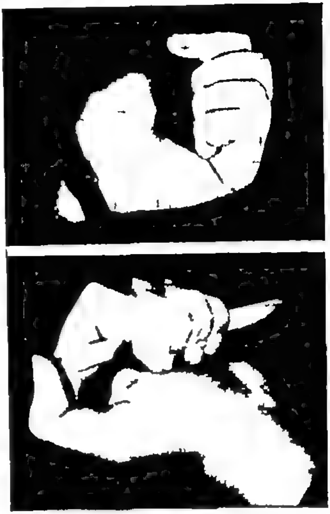


FIG. 352 Case F H.

(*Top*) Flexor profundus tendon was severed with a knife at the middle crease in the index finger six months previously Limitation of flexion is shown. The profundus tendon was recovered in the palm and united to its distal end by direct suture.

(*Bottom*) Degree of flexion four months postoperatively

The removable feature is accomplished by placing a pull-out wire under the proximal loop of the stitch. Both ends of this wire are then threaded on a curved needle and brought out through the skin proximal to the tendon juncture and left there. In three weeks the sutures where they emerge through the skin are iodized and clipped off, and a gentle pull is made on the pull out wire which straightens out and withdraws the wire suture. If there is any resistance a small rubber band is fastened to the pull-out wire and to adhesive plaster up the limb, *within 24 hours the suture* will be out. Some precautions are given on page 424

This method of suture allows a little tendon motion if the suture anchorage is made beyond the first joint distal to the suturing However, it is found that in the first two or three weeks active exercise of a sutured tendon does not hasten the healing, but instead provokes adhesion forming reaction about it. Mild exercise is started after withdrawal of the suture and in an other week the exercise can be quite free

For the flexor tendons in a hand No 34 (B & S gauge, 006 inch in diameter) is used. This is half the size of silk for the strength. It breaks at seven pounds, or at a knot at five pounds. For smaller tendons No 35 is sufficiently strong but for the large tendons such as the biceps or Achilles No 30 or 28 (012 inch in diameter) is used. In placing stainless steel wire great care should be taken never to allow it to kink, or the wire will break. As the loop of each stitch is pulled, the assistant, with a hemostat in the loop, follows in keeping the wire taut and so prevents kinking

The following are various different methods of using the removable stainless steel tendon suture

Types of Stitch, Using a Pull-out Wire END-TO-END With a No 34 stainless steel wire one foot long and with one

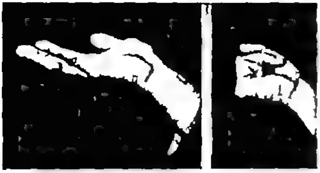


FIG. 353 Case R. H C Four months previously following severance of flexor tendons and one nerve at middle crease of ring finger there was a primary repair but subsequent rupture of the tendons. There was left only a trace of voluntary motion in the middle joint and none in the distal joint. One side was anesthetic.

At operation the tendon ends were re covered in the palm. A new tendon was placed in the finger using the flexor sublimis, and the nerve was sutured.

The illustrations show a fair result where considerable cicatrix has been present. There is 90° of voluntary flexion in the middle joint and 35° in the distal.

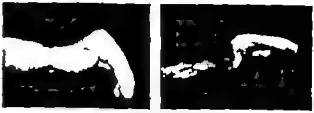


FIG 354 Case V M From a puncture of the pulp of the index finger there re sulted a severe sheath and fascial space infection involving the wrist joint and fore arm, resulting in sloughing of the extensor tendons and ankylosis of the wrist in the position of function.

A year later the head of the ulna was excised to give pronation and supination. From the tendons of the extensor carpi radialis longus and brevis grafts were placed one to encircle the ulna and tendon of the flexor carpi ulnaris tendon to pre vent displacement of the ulna one for a dorsal annular ligament of the wrist and others reaching from above the wrist to the distal part of the dorsum of the hand to extend the fingers.

The illustrations show ability to extend fingers (*left*) before and (*right*) three years after.

of the above-mentioned straight needles at each end, the first needle is thrust directly through the tendon five-eighths of an inch from its end. It is then passed back and forth through the tendon, each time crossing just a few tendon fibers and always progressing until it emerges from the ten don end as described for suturing with silk Before commencing with the second needle a seven inch piece of similar wire is laid across the suture, to be used as a pull out stitch. The second needle then also traverses back and forth through the tendon to emerge from its distal end, just as did the first, the second needle having passed through the tendon three and the first four times.

The two ends of the wire are then pulled to remove all of the slack from the tendon, and the two ends of the pull-out wire are drawn upon to narrow its loop so that it will not catch tissue when it is withdrawn The loop should not be squeezed closed with forceps unless very gently because it will break Before removing the forceps from the tendon end the pull-out wire and the suture should be pulled back and forth through the tendon, just as we do with a subcutaneous suture so that it will withdraw easily To prevent tissue growing in be tween the two pull-out wires and so hinder ing removal, these wires may be twisted Both ends of the pull-out wire are then threaded on a curved skin needle, which is passed on up the tendon sheath and on out through the skin, where the pull-out wires are left in place. The two suture ends are then threaded by their needles longitudinally down the center of the distal part of the tendon for an inch or more. To do this, the tendon is nipped at its tip with a Kocher hemostat which is rotated a little and draws the tendon taut. The part of the tendon held by the hemostat is then cut off The sutures then pass on up the sheath a little and then on diagonally out through the skin, for external anchorage. If this is near the end of a finger, one of the needles is passed diagonally through the fingernail

and the sutures are tied over the nail Otherwise, the sutures may be run through some adhesive plaster attached to the skin and tied over the crossbar or a button The distal border of the palm between the fingers is an excellent place for such a button If the suturing is done in the forearm, the sutures are brought out through the annu

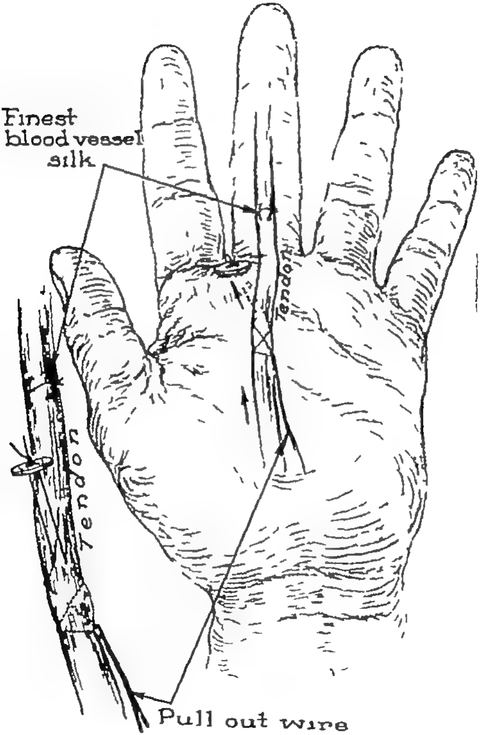


FIG. 355 "Suture at a distance." The removable stainless-steel wire holds the proximal tendon end distalward relieving the juncture which is of finest silk for apposition, entirely free from strain or adhesion producing suture. *This silk approximation suture is rarely needed.* Method applies especially to primary repair in narrow tunnels where otherwise adhesions are inevitable.

FIG. 353 Case R H. C. Four months previously following severance of flexor tendons and one nerve at middle crease of ring finger there was a primary repair but subsequent rupture of the tendons There was left only a trace of voluntary motion in the middle joint and none in the distal joint. One side was anesthetic.

At operation the tendon ends were re covered in the palm. A new tendon was placed in the finger using the flexor sublimus, and the nerve was sutured.

The illustrations show a fair result where considerable cicatrix has been present. There is 90 of voluntary flexion in the middle joint and 35 in the distal.

FIG 354 Case V M. From a puncture of the pulp of the index finger there resulted a severe sheath and fascial-space infection involving the wrist joint and fore arm, resulting in sloughing of the extensor tendons and ankylosis of the wrist in the position of function.

A year later the head of the ulna was excised to give pronation and supination. From the tendons of the extensor carpi radialis longus and brevis grafts were placed one to encircle the ulna and tendon of the flexor carpi ulnaris tendon to prevent displacement of the ulna one for a dorsal annular ligament of the wrist and others reaching from above the wrist to the distal part of the dorsum of the hand to extend the fingers.

The illustrations show ability to extend fingers (*left*) before and (*right*) three years after

of the above mentioned straight needles at each end the first needle is thrust directly through the tendon five-eighths of an inch from its end It is then passed back and forth through the tendon each time crossing just a few tendon fibers and always progressing until it emerges from the ten don end as described for suturing with silk. Before commencing with the second needle a seven-inch piece of similar wire is laid across the suture to be used as a pull out stitch. The second needle then also traverses back and forth through the tendon to emerge from its distal end, just as did the first, the second needle having passed through the tendon three and the first four times

The two ends of the wire are then pulled to remove all of the slack from the tendon, and the two ends of the pull-out wire are drawn upon to narrow its loop so that it will not catch tissue when it is withdrawn. The loop should not be squeezed closed with forceps, unless very gently, because it will break. Before removing the forceps from the tendon end the pull-out wire and the suture should be pulled back and forth through the tendon, just as we do with a subcutaneous suture so that it will withdraw easily To prevent tissue growing in be tween the two pull-out wires and so hinder ing removal, these wires may be twisted. Both ends of the pull-out wire are then threaded on a curved skin needle, which is passed on up the tendon sheath and on out through the skin, where the pull-out wires are left in place. The two suture ends are then threaded by their needles longitudi nally down the center of the distal part of the tendon for an inch or more. To do this, the tendon is nipped at its tip with a Kocher hemostat which is rotated a little and draws the tendon taut. The part of the tendon held by the hemostat is then cut off The sutures then pass on up the sheath a little and then on diagonally out through the skin, for external anchorage. If this is near the end of a finger, one of the needles is passed diagonally through the fingernail

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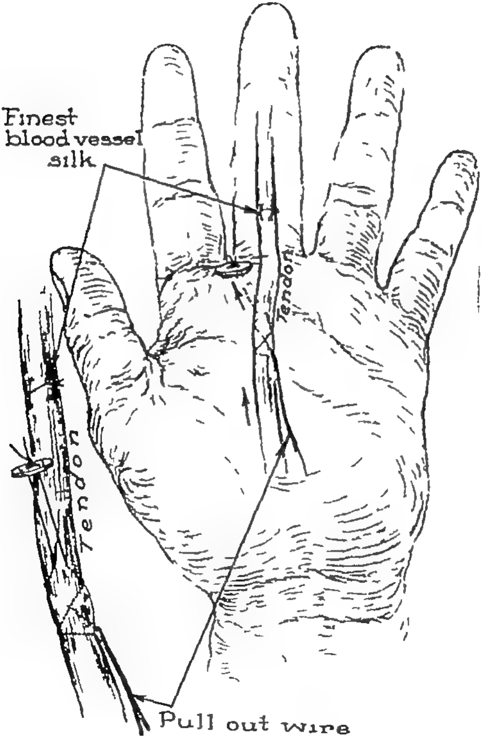


FIG. 355 "Suture at a distance." The removable stainless-steel wire holds the proximal tendon end distalward relieving the juncture which is of finest silk for apposition, entirely free from strain or adhesion producing suture. This silk approximation suture is rarely needed Method applies especially to primary repair in narrow tunnels where otherwise adhesions are inevitable.

FIG. 353 Case R. H C. Four months previously following severance of flexor tendons and one nerve at middle crease of ring finger there was a primary repair but subsequent rupture of the tendons. There was left only a trace of voluntary motion in the middle joint and none in the distal joint. One side was anesthetic.

At operation the tendon ends were re covered in the palm. A new tendon was placed in the finger using the flexor sublimis, and the nerve was sutured.

The illustrations show a fair result where considerable cicatrix has been present. There is 90 of voluntary flexion in the middle joint and 35 in the distal.

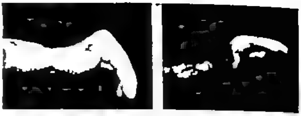


FIG 354 Case V M. From a puncture of the pulp of the index finger there re sulted a severe sheath and fascial-space infection involving the wrist joint and fore arm resulting in sloughing of the extensor tendons and ankylosis of the wrist in the position of function.

A year later the head of the ulna was excised to give pronation and supination. From the tendons of the extensor carpi radialis longus and brevis grafts were placed one to encircle the ulna and tendon of the flexor carpi ulnaris tendon to prevent displacement of the ulna one for a dorsal annular ligament of the wrist and others reaching from above the wrist to the distal part of the dorsum of the hand to extend the fingers.

The illustrations show ability to extend fingers (*left*) before and (*right*) three years after

of the above-mentioned straight needles at each end, the first needle is thrust directly through the tendon five-eighths of an inch from its end. It is then passed back and forth through the tendon each time crossing just a few tendon fibers and always progressing until it emerges from the ten don end, as described for suturing with silk. Before commencing with the second needle a seven-inch piece of similar wire is laid across the suture to be used as a pull out stitch The second needle then also traverses back and forth through the tendon to emerge from its distal end, just as did the first, the second needle having passed through the tendon three and the first four times.

The two ends of the wire are then pulled to remove all of the slack from the tendon, and the two ends of the pull-out wire are drawn upon to narrow its loop so that it will not catch tissue when it is withdrawn. The loop should not be squeezed closed with forceps unless very gently, because it will break Before removing the forceps from the tendon end the pull-out wire and the suture should be pulled back and forth through the tendon, just as we do with a subcutaneous suture so that it will withdraw easily To prevent tissue growing in between the two pull-out wires and so hindering removal, these wires may be twisted. Both ends of the pull-out wire are then threaded on a curved skin needle, which is passed on up the tendon sheath and out through the skin, where the pull-out wires are left in place. The two suture ends are then threaded by their needles longitudinally down the center of the distal part of the tendon for an inch or more. To do this, the tendon is nipped at its tip with a Kocher hemostat which is rotated a little and draws the tendon taut. The part of the tendon held by the hemostat is then cut off The sutures then pass on up the sheath a little and then on diagonally out through the skin, for external anchorage. If this is near the end of a finger, one of the needles is passed diagonally through the fingernail

and the sutures are tied over the nail Otherwise, the sutures may be run through some adhesive plaster attached to the skin and tied over the crossbar or a button The distal border of the palm between the fingers is an excellent place for such a button If the suturing is done in the forearm, the sutures are brought out through the annu

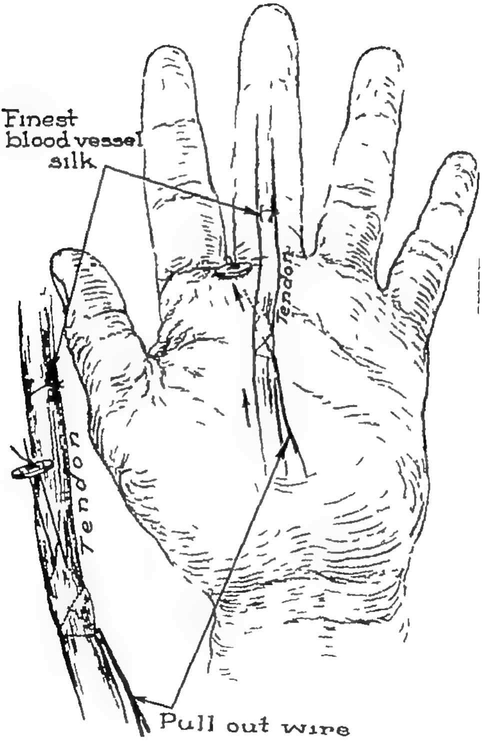


FIG. 355 "Suture at a distance." The removable stainless-steel wire holds the proximal tendon end distalward relieving the juncture which is of finest silk for apposition, entirely free from strain or adhesion producing suture This silk approximation suture is rarely needed. Method applies especially to primary repair in narrow tunnels where otherwise adhesions are inevitable.

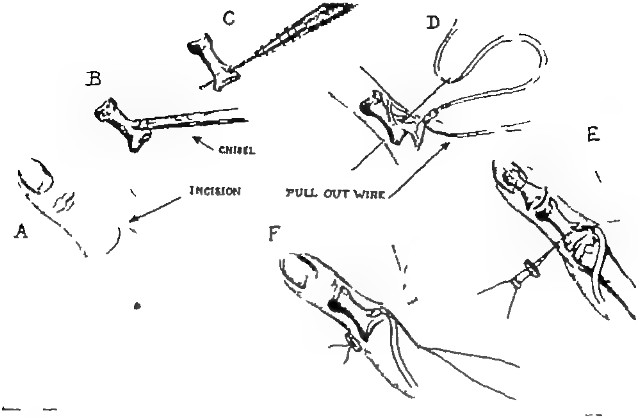


FIG. 356 Method of attaching tendon to bone, using removable stainless-steel wire as used in the pulley operation for opposition of the thumb or the tendon T operation. There is tendon-bone contact. The wire penetrates the digit or limb and is tied over a button outside the skin The suture in three weeks is withdrawn by the pull-out wire.

lar ligament and fastened by a button outside the heel of the palm.

END-TO-END SUTURE AT A DISTANCE. The object of this is to have the suture in the tendon remote from the tendon juncture so as to minimize the tissue reaction at the latter The suture is placed exactly as in the end to-end type, but at a distance proximal to the juncture, and is then passed down the tendon sheath, out the skin, and anchored at such tension that the tendon ends will be in approximation These ends may then be attached to each other with a simple double right angle stitch of the finest blood vessel silk, merely for approximation and not for holding. Usually the tendon ends will lie together without the necessity of any approximation suture. The suture "at a distance" is advisable when our tendon juncture is in a narrow tunnel as in a finger where adhesions caused by the presence of a suture would be a detriment. The pull-out wire is placed as above.

Another method of suturing 'at a distance' is to thread the wire sutures with the needles down the center of the proximal tendon, on through the distal tendon end to which it is being joined, and then diagonally out through the skin for anchorage. This holds the tendon ends in exact approximation.

TENDON TO-BONE. In fastening a tendon to a bone in a hand or elsewhere, a simple method is first to chip up an osteoperiosteal flap from the near surface of the bone, then to drill the bone here and pass a straight needle with the two tendon suture ends right through the hole in the bone and out the skin on the opposite side of the limb The limb is then flexed so the tendon end can be drawn snugly against the raw bone, as the wires are passed through two holes of a button and are tied over the crossbar A pull-out stitch is placed as usual. To facilitate withdrawal the hole should be drilled in the bone obliquely in the line of the pull-out

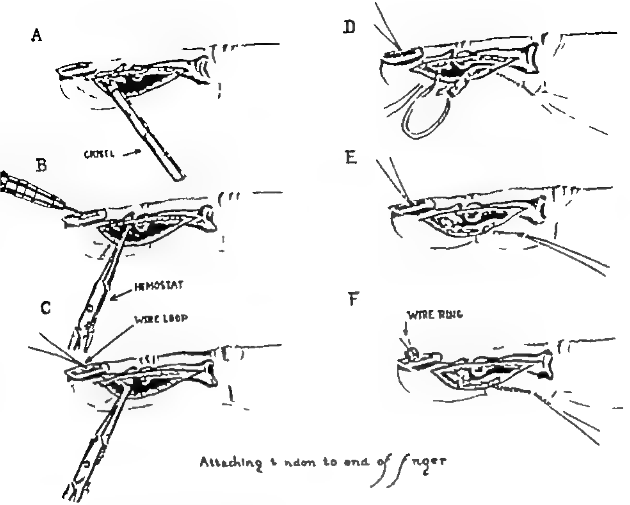


FIG. 357 Method of attaching a tendon to the distal phalanx.
(A) Surface of bone is denuded.
(B) Drill penetrates nail and bone and is clasped by a hemostat.
(C) On withdrawing drill a wire loop is passed to the awaiting hemostat.
(D) With the loop the tendon sutures are drawn through.
(E) The tendon is snugged to denuded bone.
(F) Sutures are tied over a wire ring. The pull-out wire withdraws the stainless-steel suture after three weeks.

wire instead of at a right angle to it. A convenient method if a drill is not available is to drill with a Kieth needle, mounted longitudinally in a Kocher's hemostat. The tendon needles are then passed through the eye of the Kieth needle, cut off and the tendon sutures are pulled through the bone Another method is to place a fine Kirschner wire in a pin drill The wire may be bitten off obliquely for a point. The end emerging from the pin drill is bent at a right angle to grasp for drilling To be successful, there should be intimate tendon to-bone juncture free from interposed tissue When a tendon is placed through a drillhole in bone the part of it in the bone becomes bone by replacement and metaplasia This method is readily adapted to join tendons or ligaments to bone anywhere in the body, as are also the methods of tendon suture

ATTACHING FLEXOR TENDON TO DISTAL PHALANX IN A FINGER. Through our lateral incision the volar aspect of the distal phalanx is first scraped with a small chisel With a dental finger drill a hole is made diagonally, penetrating the dorsum of the nail and the phalanx, emerging where the latter was scraped. A curved mosquito hemostat then grasps the protruding point of the drill, it is released enough to with-

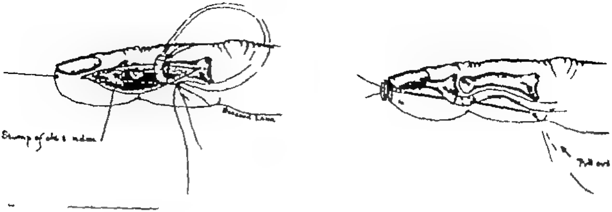


FIG. 358 Method of attaching a tendon to the distal phalanx in a finger utilizing the stump of the old tendon and using removable stainless-steel wire.

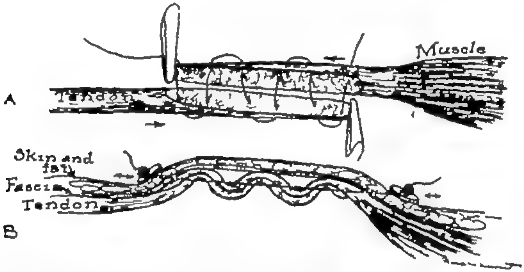


FIG. 359 Running suture of removable stainless-steel wire for use in joining tendons side-to-side. The wire is tightened and fastened by two shot. This straightens the wire but makes the tendon undulate. Wire withdrawn without resistance.

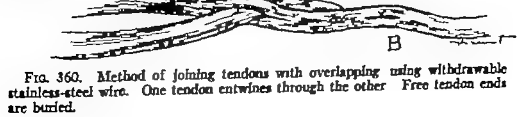


FIG. 360. Method of joining tendons with overlapping using withdrawable stainless-steel wire. One tendon entwines through the other Free tendon ends are buried.

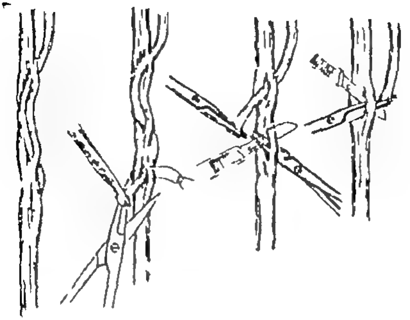


FIG. 361 Method of making a lateral juncture of one tendon into another by interweaving. No tendon end is left free to cause aberrent attachment and so to limit motion. The single knot is sunk into the tendon or instead a running with drawable stainless steel wire is used as in Fig 360 A dissecting probe for making the slits is better than a knife.

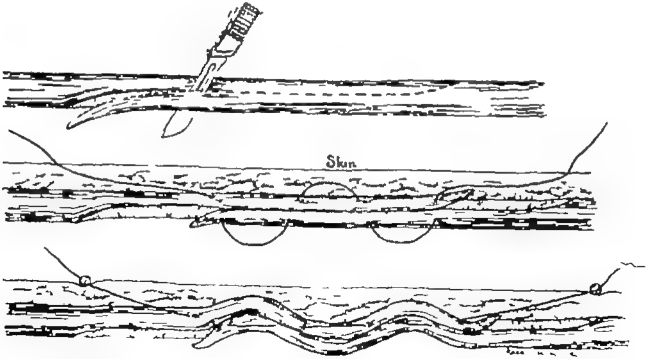


FIG. 362 Lengthening a tendon and securing it with a running stainless-steel wire which is withdrawn in three weeks.

FIG. 363 Case M S While skinning a deer the knife lacerated across the base of the little finger The wound healed per primam and a month later while lifting a sheep he could no longer flex his finger

(*Left*) Showing lack of flexion after secondary tendon rupture. At operation both flexors were found severed at the proximal pulley The sublimis tendon was removed but the profundus tendon was united directly using removable stainless-steel wire and fastening it to a button down the side of the finger

(*Right*) Degree of flexion obtained three months later

draw the drill, but is held in place until a loop of fine wire is passed through the drill hole. On closing the hemostat the wire loop is withdrawn into the finger Our suture has already been placed in the end of the tendon together with a pull-out wire, the two strands are passed through the loop and drawn out through the drillhole, there to be tied on the surface of the fingernail over a tiny wire ring. This holds the tendon ends snugly against the scraped bone on the volar aspect of the phalanx, giving it tendon to-bone juncture. The wire loop is used instead of a shot because in dressings the latter is moved so frequently that the wire suture might break. The pull-out wire has been placed to withdraw the suture in three weeks.

An excellent and still simpler method is to preserve the stump of the flexor tendon cut squarely off at its insertion The needles on the tendon suture are passed through this and on out the tip of the finger carrying the sutures which are there tied over a button a pull-out wire being placed as usual.

Removable Running Wire Suture SIDE-TO-SIDE UNION This type of suture is useful when the juncture is not made in a closed tunnel and where the tendon ends can be overlapped, such as in the dorsum of the hand and in the forearm It is used in joining, lengthening, and in shortening tendons Each tendon end is first tapered by a long oblique cut, these raw surfaces are approximated, a No 34 steel wire enters the limb through the skin proximal to the tendon juncture and is then made to pass back and forth through the two overlapping tendon ends through the length of their overlapping and is then brought out through the skin distal to the tendon juncture. On pulling taut the two ends of the wire which are then outside the skin, the wire straightens and can be drawn freely back and forth. A shot is then placed on each wire where it emerges from the skin The wire is then straight, but the tendon is zig zag At the end of three weeks one end of the wire under the shot is cut off the wire is easily withdrawn by its other end The tendon will then be firmly united and free from suture.

SIDE TO-SIDE SUTURE BY INTERWEAVING THE TENDONS Where tendon ends are joined by overlapping one tendon can be passed back and forth through slits made in the other tendon, to give intimate contact and a splicing effect. The removable running stitch is then placed just as in the side to-side stitch.

END-TO-SIDE JUNCTURE. This is useful in transferring one tendon to another or in imbedding a tendon end in an adjoining tendon, so as not to leave any free, unsatisfied tendon end lying around for aberrant attachment. The dissecting probe or a pointed scalpel is thrust through the host tendon and followed by a mosquito hemostat which draws back the end of the other tendon through the host tendon This is repeated once farther distally, and one stitch of No 36 wire is passed through both tendons and back and tied to hold them in place. This is all that is required because there is usually not much tension to withstand but if there will be tension a with-

drawable running stitch can be used The projecting end of the tendon so imbedded is then tucked within the host tendon and the slit in the latter is closed with a stitch of No 00000 catgut, which will be gone in a couple of days The union takes place, not where the tendons are woven, but at the unsatisfied end of the tendon that is embedded.

Making Pulleys. From loss of the transverse carpal or the dorsal carpal ligaments, the flexor or extensor tendons will bow across the wrist on flexion or dorsiflexion respectively, thus losing their efficiency Such new ligaments are readily constructed, using either a band of fascia lata or a tendon graft and contacting it at the sides of the wrist to ligament or bone. The two pulleys in the flexor aspect of a finger are important. The proximal one, really of two parts separated at the proximal joint, commences at the head of the metacarpal and reaches about 1⅛ inches to just beyond the middle of the proximal phalanx. The distal one which is opposite the center of the middle phalanx is five-eighths of an inch long. Either of these can be reconstructed quite simply with a free tendon graft made to loop around the flexor tendons and either the metacarpal or the middle phalanx under the extensor tendons. To do this, a curved mosquito hemostat is passed through a small stab wound through part of the circumference and out another stab wound 90° farther around. As it is withdrawn the tendon graft is dragged after it By a similar maneuver at each of the four aspects of the finger, the graft is made to complete the circle It is sutured to itself with two interrupted buried sutures, and this juncture is swung around to the side For a middle segment pulley one slip of sublimis may be spared and looped over the profundus tendon to be sutured to the other side of the finger

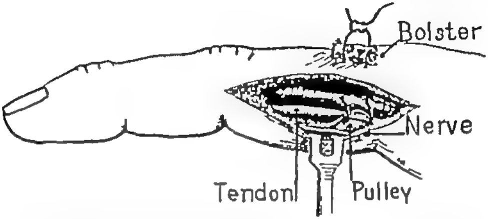


FIG. 364 Repairing an annular ligament or pulley using removable stainless-steel wire tied over a bolster to minimize the tissue reaction compared with that from silk or catgut.

In closing a lateral incision along a finger in which the cut through an annular band also needs repairing, instead of burying a trouble-making catgut knot the following is a simple method the wire suture enters through the skin of the finger dorsal to the incision, passes through periosteum, catches by mattress stitch the volar edge of the pulley and passes back along a similar course to be tied over a tiny bolster As the knot is tied the ligamentous sheath is drawn between the nerve and tendon to the side of the phalanx reforming the pulley This principle of using withdrawable stainless-steel wire, in order to avoid leaving catgut and its knots, has very wide applications, such as closing dead spaces repairing abdominal wounds, ventral hernias, fascia and in tendon work throughout the limbs

Tension for Suturing Tendons A freshly cut tendon is sutured at normal tension—that is, according to Mayer's rule, when the origin and insertion of the muscle are made to approach as near to each other

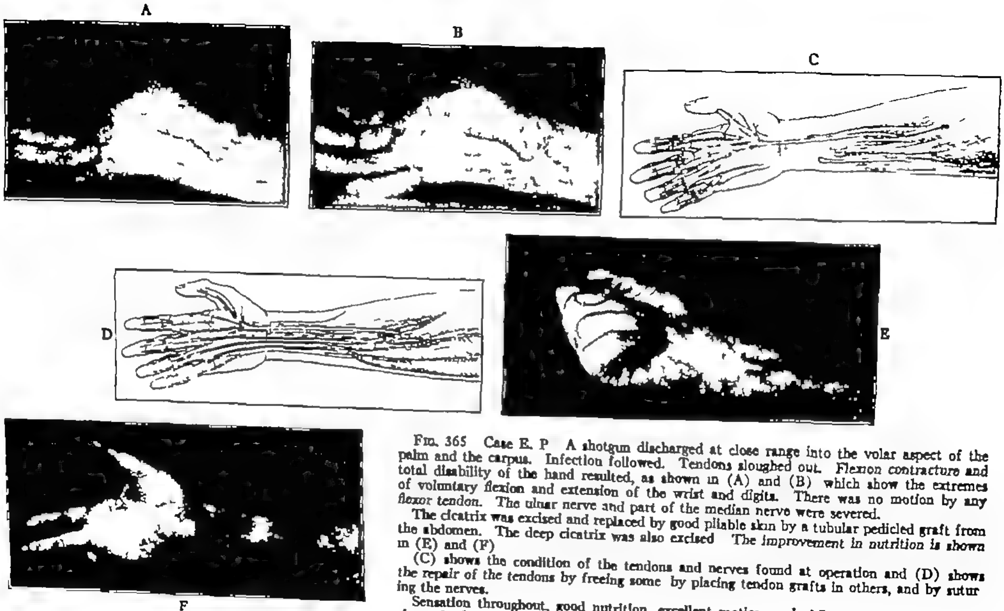


Fig. 365 Case E. P A shotgun discharged at close range into the volar aspect of the palm and the carpus. Infection followed. Tendons sloughed out. *Flexion contracture* and total disability of the hand resulted, as shown in (A) and (B) which show the extremes of voluntary flexion and extension of the wrist and digits. There was no motion by any *flexor tendon.* The ulnar nerve and part of the median nerve were severed.

The cicatrix was excised and replaced by good pliable skin by a tubular pedicled graft from the abdomen. The deep cicatrix was also excised *The improvement in nutrition is shown* in (E) and (F)

(C) shows the condition of the tendons and nerves found at operation and (D) shows the repair of the tendons by freeing some by placing tendon grafts in others, and by suturing the nerves.

Sensation throughout, good nutrition excellent motion, *and ability to work resulted as* shown in (E) and (F) (Courtesy Jour Bone and Joint Surg., *14.35 Jan 1932*)

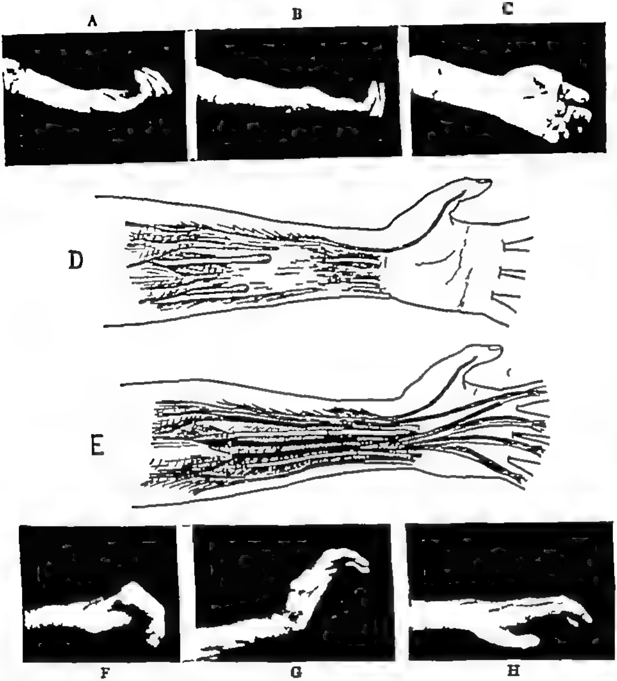


FIG. 366 Case H. N. All tendons and nerves in volar aspect of forearm were severed except the flexor longus pollicis as he fell with his arm through a window Infection followed. Hand was completely disabled.

(A, B and C) Showing limits of flexion and extension of wrist and fingers, loss of opposition of the thumb and claw deformity Anesthesia of median and ulnar areas was complete.

Four months later the median nerve which gaped 1½ inches, and the ulnar which gaped five inches, were sutured after rerouting the ulnar nerve and flexing the elbow

Ten months later the flexor tendons were repaired freeing them from cicatrix, suturing placing four grafts of fascia lata, and inspecting the nerve sutures.

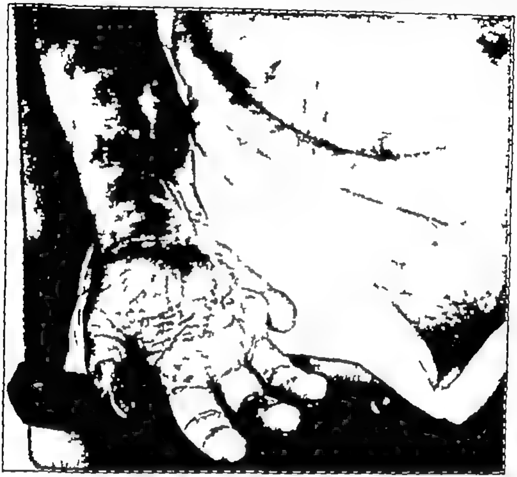
(D and E) Showing the condition found and what was done. Black lines indicate grafts.

Sensation to light touch and pinprick returned throughout by 14 months In a year and eight months opposition had returned to the thumb clawing was less the interosseus and hypothenar muscles were acting and he was able to work steadily

(F G and H) Taken at that time show flexion, extension, and opposition of the thumb

as possible the tension should be zero This does not hold for late repairs, as here the muscle will have already contracted If the time from the accident is within two months, the cut tendon ends can be sutured together The tendon will then be a little taut for full extension, but as soon as it is healed it will gradually draw out the muscle to the normal degree. *After two months from the injury a tendon graft or transfer will have to be resorted to because, with few exceptions, the tension will be too great for the tendon ends to be directly sutured. If the transfer is done to one or several of the digitorum tendons, the tension should be so adjusted that the fingers will, under the same muscle pull, each be flexed to such a degree that all will be in alignment.*

In using a free graft to bridge a tendon we must allow for some shrinking which will take place in the graft. Otherwise, in repairing a flexor tendon to a finger, the finger will eventually be in too great flexion The method of estimating when using a graft is to place the wrist and finger almost straight out. The tendon ends should then be joined at only a slight degree of tension At first, the finger will be a little *more extended than are the other fingers,*



A

FIG. 367 (A) Case S T While this man was drawing a shotgun toward him the charge entered the palm and forearm. Infection followed, and the flexor tendons of the palm and forearm and six inches of the median and ulnar nerves sloughed out.

The illustration shows the contracted and totally disabled hand after healing, and also the tubular pedicle of abdominal skin ready for grafting There was no motion or sensation in the hand except from the radial nerve and the extensor tendons. (Courtesy Jour Bone and Joint Surg., 14.36 Jan., 1932)

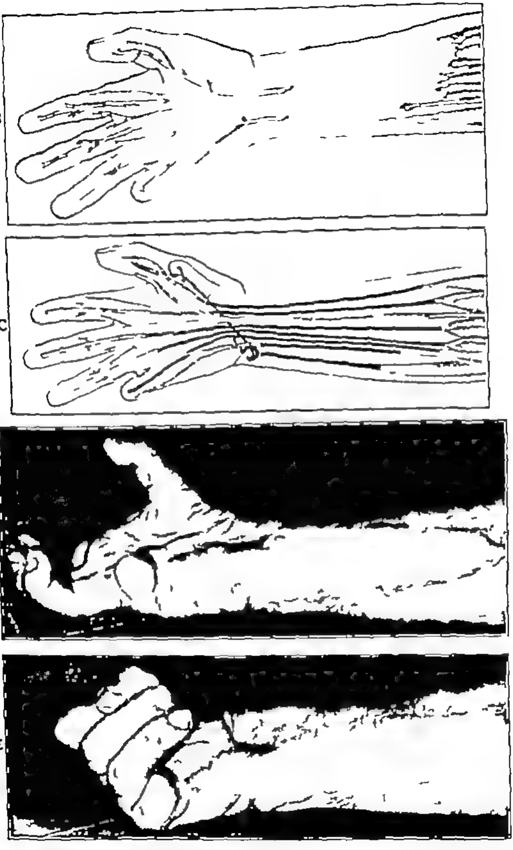


Fig. 367 (B to E) Showing the condition found at operation after dissecting out the cicatricial tissue. There are wide gaps in all the flexor tendons and in the median and ulnar nerves. The pedicled skin graft was applied and later tendon grafts from the extensors of the toes and nerve grafts from the sural nerves were placed, as shown in (C) A pulley operation was also done as shown, to regain opposition of the thumb Good function resulted, as shown in (D) and (E) and the patient was able to return to work as a welder (Courtesy Jour Bone and Joint Surg., 14:36 Jan., 1932.)

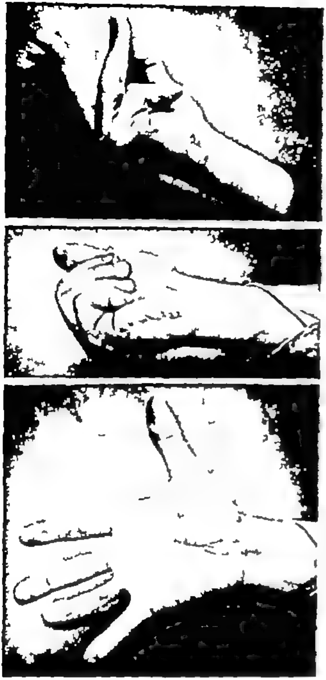


FIG. 368 Case E. L. Every finger was lacerated across its proximal segment three months previously by a sheet of tin severing all the flexor tendons of all the fingers except a portion of the sublimis in the little. The wound healed per primam.

(*Top*) Limit of flexion preoperatively At operation all flexor tendons were removed from all the fingers. The four flexor sublimis tendons were withdrawn in the forearm and each was used as a free graft to prolong its respective profundus tendon from palm to distal phalanx. Each stump of sublimis in forearm was sutured to its profundus tendon for added strength.

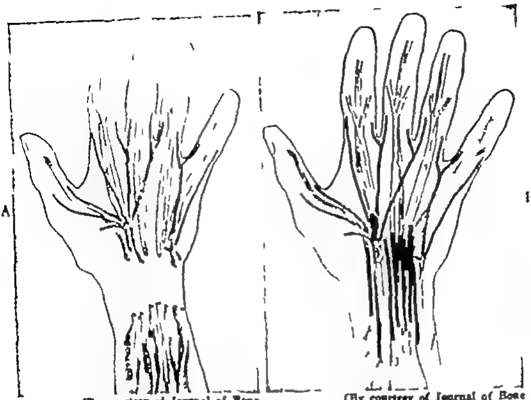
(*Center* and *Bottom*) Function 10 mos. later Distal joints tested separately flexed for the index to little finger 45 42 41 and 50°

but gradually as the graft shrinks it will come into alignment with them

When the muscle has limited amplitude the tendons should be joined under that tension which will place the limited range of motion where it will be most useful When a muscle has been long relaxed, due to severance of its tendon, allowance should be made for some limitation of amplitude from its normal excursion. The tension should be adjusted for the most useful range of motion The muscle that has been long relaxed has a limited range. A little tension on the tendon will encourage the muscle to elongate to some degree. When a muscle retracts half its length, its strength is gone. It has greatest strength when the limb to be moved is in the middle of its range of motion. This, in a finger when the wrist is straight, is a mildly flexed position. The muscle should allow full extension from this and contract to full flexion. If placed under too much tension, it loses strength and if under too little tension, it will have no power to contract. Allowance should be made if the muscle has been long relaxed so that postoperatively it can to some extent be drawn out and in a compensatory way adapt its contractility to its shortening. Strength of a muscle is in proportion to its cross section, but excursion is in proportion to its length. Tension of a muscle increases as it is drawn out up to a certain point but reduces to nothing when the muscle has contracted to 57% of its length. This applies to the immediate time when the muscle becomes contracted In time there is some compensation.

Splinting After Tendon Suture After repairing a flexor tendon anywhere in its course from wrist to fingertip, the same splinting can be used, namely, a slab of plaster of Paris placed over the dorsum of the wrist, hand, and forearm, ending at the proximal knuckles. This should keep the wrist in flexion, but should leave the fingers free to move. With the wrist in flexion, the flexor muscles will be robbed of

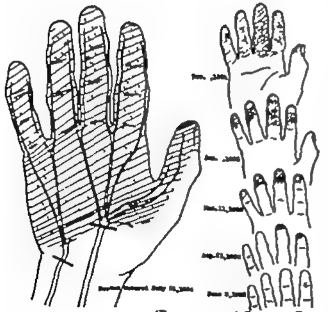
A



B

(By courtesy of Journal of Bone and Joint Surgery)

(By courtesy of Journal of Bone and Joint Surgery 1014 Jan., 1928.)



(By courtesy of Surgery Gynecology and Obstetrics, 44:146.)

C

FIG. 369 Case A. L., aged 54 Five months previously a forest bit and infection destroyed all of the tendons and nerves in the front of the wrist. Ends of ulnar nerve were an inch apart and median three inches. Nutrition of the hand was poor On July 21 1924 the two nerves were sutured where indicated, and nine ten don grafts from the ex tensors of the toes were used to bridge the tendons, as shown in (A) (B) and (C)

Anesthesia to cotton wool (shaded) and anal gesia to pinprick (dotted) receded, as shown by the dates on the diagrams. The power of opposition returned to the thumb as it does in about 66 per cent of cases of repair by suture of the median nerve. Enough movement returned in the fingers and thumb to allow the hand to open about three inches and to grasp firmly It would have been better to use few tendon grafts and paratenon beneath them.

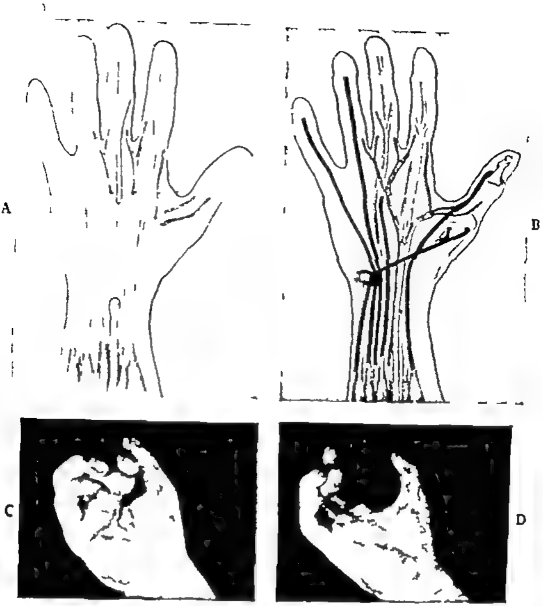


FIG. 370 Case P K. *Five months previously from a knife cut in the* pulp of the thumb the contents of the hand and forearm were destroyed by severe infection, which lasted three months. The median nerve and most of the tendons sloughed. The ulnar nerve was spared, but the small hand muscles were practically destroyed. When presented for operation the wrist and fingers were straight and stiff The thumb was lateral without opposition and could not touch any finger He could not move the thumb or any finger had no sensation in the area supplied by the median nerve, and the hand was indurated and of poor nutrition. After the joints were first drawn into functioning positions two operations were performed.

Operation (in two stages four months apart) At operation the hand and wrist were found to be composed largely of scar tissue. In (A) is shown the findings as regards the flexor tendons and the median nerve. In (B) is shown what was done. In black are shown the tendon grafts taken from the long extensors of the toes. A pulley operation was done to give the thumb opposition. The median nerve was split and sutured to five of its branches. The cicatrix was excised. A capsulectomy was done on the proximal finger joints and a large sheet of paratenon fat was taken from over the triceps tendon and grafted about the flexor tendons in the wrist and base of the palm, separating each from the other and from the surrounding tough tissue. The extensor tendons of the thumb were freed.

Result Sensation, including stereognosis was restored over the entire area. The ability to open and close the hand is shown in (C) and (D) His grip is 15 kilograms. He shovels coal for a living, and he can pick up articles ranging from a match to an object two and one-half inches in diameter (Courtesy Jour Bone and Joint Surg., *10 12 Jan., 1928.*)

strength, but still can undergo a little exercise of movement. The wrist joint should not be thus fixed in forced flexion, because such a strain injures the joint We should flex the wrist to the full degree and then back off slightly as the plaster hardens A gauze bandage holds the plaster in place.

In splinting for repaired extensor tendons of the fingers, whether repaired in the finger, in the dorsum of the hand, or in the forearm, the plaster slab is laid on the flexor surface of the forearm and hand and reaches to the distal creases in the digits The wrist is then held in dorsiflexion and the fingers in full extension, less a little allowance so as to relieve all strain If it is the long extensor tendons that are sutured in the dorsum of the hand or forearm, the splinting need not be beyond the middle finger joints. This is advantageous because it will keep the distal two joints of the fingers mobile, and so prevent stiffness

SPECIAL TENDONS

Tendons are frequently injured by severance or by sloughing from infection. Severance of all tendons across the forearm is frequent from bottles, windows, and wind shields, in the palm, from bottles and porcelain faucets, and across the proximal segment of the fingers by knives and glass From infection in a digital sheath a tendon often sloughs from the length of a finger and from severe infection in the palm, wrist, and forearm the tendons may slough from one to three inches above the wrist to the distal part of the palm, or some even to the ends of the digits. The densest scars are found under the annular ligaments in the wrist and throughout the digits

In Forearm (Flexors)

Primary or secondary repair of tendons in the forearm is usually quite successful because there is enough loose surrounding tissue about the junctures to allow motion. Frequently, sublimis tendons are severed here and their loss is not noticed Rejoining to themselves, through the medium of paratenon, takes place promptly Disability from profundus tendons is more conspicuous If all tendons are severed and no primary suture is done great disability results Infection here following suture is often very disabling Frequently, overproliferation of paratenon following an injury or infection will greatly hinder motion In extensive tendon injury usually severance of the median or ulnar nerve, or both, adds to the crippling in the hand, requiring repair When a flexor tendon becomes adherent to a median nerve, the intermittent tugging on the nerve may result in a painful condition From proliferation of paratenon the patient may complain of discomfort as one tendon snaps over the other while in action.

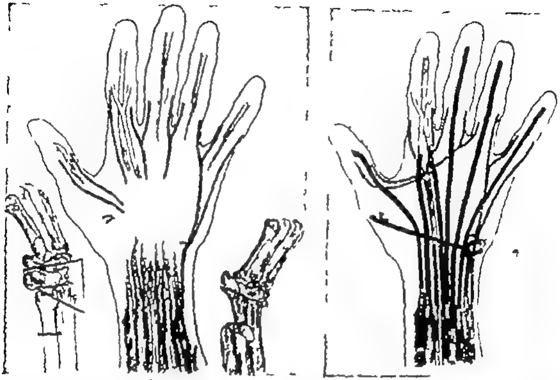
On opening the forearm, the flexor tendons to the fingers will be found rather ulnarward to make room for the flexor carpi radialis. Sublimis tendons are recognized by the separate pointed muscle bellies, which reach farther distalward than the deeper square-cut bellies of the profundus tendons The sublimis tendons are in two planes, those showing superficially being to the long and ring fingers, with the muscle for the long finger spreading fan-like superficially across the forearm from radius to inner epicondyle The tendons to the index and little fingers are deeper and that to the index crosses under the tendon to the long finger The sublimis tendon, being more individually muscled and free from interdigitations can be withdrawn from the palm separately and easily, and attachment of one tendon does not hold back the action of the others

The profundus tendons fan out as they progress distally in interdigitating slips. Therefore, they cannot be withdrawn from the palm by pulling on their proximal ends but can be if their distal ends are passed up proximalward and withdrawn in the forearm.

When repairing the long flexor tendons in the forearm often it is found that a pull on them does not flex the digits, due to light adhesions within the fingers. These may be freed by flexing the fingers completely and then pulling on the tendons. To free the tendon *in the distal part of the finger* it may be necessary first to hold the proximal and middle joints in extension and the distal joint in flexion when this pull is made, and similarly with the middle joint. When much cicatrix is present, it is advisable to excise the transverse carpal ligament.

In Palm

The incision for exposure follows the distal crease in the palm and then turns proximalward to the center of the heel of the palm, penetrating through the palmar fascia. First the vessels and nerves, which are superficial to the tendons, are located and spared. Frequently, these nerves to the thumb and fingers have been severed along with the tendons and should be repaired.



A B

FIG. 371 Case H. O., aged 36 Two years previously from a sliver in the volar part of the thumb an infection caused all the flexor tendons and much of the median nerve to slough from the hand sparing the ulnar nerve only The carpus and radio-ulnar joint were ankylosed straight, the proximal finger joints were stiff and straight. The median area was anesthetic and there was no power of flexion even from the small hand muscles.

Operation (in two stages a year apart) An excision was made of the scar tissue from hand and wrist, the carpus, and the lower end of the ulna. Pronation and supination were then free, the wrist was wired for ankylosis in a cock up position, and the wrist was so shortened that when the elbow was flexed the median nerve could be sutured to its five branches. At the second operation eight tendon grafts, some eight and one half inches long, were taken from the extensors of the toes and used to reconstruct the flexor tendons, including a pulley operation for opposition of the thumb

In (A) and (B) are shown the condition found and the reconstruction done.

Result Although the state of nutrition in this hand was poor sensation returned throughout and some degree of stereognosis. The wrist was ankylosed in a functioning cock up position, and pronation and supination were complete. Opposition was restored to the thumb. The grip was 15 kilograms and the spread between the thumb and the fingers was two inches. He was able to earn his living again as a carpenter (Courtesy Jour Bone and Joint Surg., 10 13 1928.)

The sublimis tendons are smaller and are superficial to the profundus tendons, which have the lumbrical muscles attached to them. In the central part of the palm, the septum enclosing the soft, thin paratenon tissue is split through laterally, exposing the sublimis and profundus tendons In the distal and proximal parts of the palm, sheath formation is present

Tendon junctures in the distal part of the palm are more apt to become adherent than in the proximal part, as above mentioned. Lumbrical and interosseus muscles can be used to advantage to cover up these tendons or to separate them and prevent adhesions. A tendon juncture made in the region of the annular sheath or pulley opposite the metacarpal head is sure to become firmly adherent. It is better to resort to a tendon graft extending from the base of the palm to the end of the finger In this region opposite the head of the metacarpal, the overlying tendon sheath seems to be most vulnerable to injury and is frequently the site of Dupuytren's contracture, tumor, tuberculosis, ganglion, and trigger finger Tendon junctures should be nearer the base of the palm, and there each is wrapped with a lumbrical muscle

Trigger Finger

Due to repeated or single traumatisms to the tendon as it passes over the head of the metacarpal, especially that of the ring and long fingers, a swelling occurs in the sublimis tendon and its epitenon just where it forks and straddles the profundus tendon In some cases a little ruptured hypertrophied tab of part of the sublimis tendon is here found and in others there is a mere thickening of the epitenon or the connective tissue within the tendon itself In addition, the annular sheath through which the tendon glides may itself become thickened, thus narrowing its caliber at this site. The patient notices the gradual onset of trigger finger phenomenon When the finger is about two-thirds flexed some resistance is met and with a snap the finger flexes completely Similarly, on extending the finger the lump of the tendon is held up in the narrow part of the sheath until it snaps through Finally, the finger either will not flex completely or is held in flexion Discomfort or slight pain accompany the snapping and a tender lump can be felt slipping beneath the examining finger It is frequent in women who take over a man's work, especially when using a stinger in welding We had several cases of trigger thumb in infants, one of which was bilateral, and one of multiple creaking tendons and trigger fingers in a girl of ten years

To correct the condition a short incision paralleling the distal crease in the palm allows one actually to see the phenomenon taking place The tendon is withdrawn from the sheath sufficiently to inspect the cause of the lump If a tab is present it should be excised well into the tendon by a V-cut and slit far back from the pulley, so if a new tab forms from the unsatisfied end of a tendon bundle it will be in the palm Usually there is just a general thickening of the sublimis where it forks just distal to the constricting sheath, though the profundus may be involved.

In acute cases one sees an edematous, inflamed epitenon covering this area of the tendon and the septa of endotenon penetrating between the tendon bundles appear homogeneous, thick, and bluish white, expanding the tendon. It is difficult to dissect this out and it can be done only partially It is best not to cut into this tendon, instead, the sheath, which is also thickened, should be slit through laterally with a pointed scalpel, cutting from the inside outward but avoiding the nerve. If a larger space for passage of the tendinous thickening is desired, a second slit may be made through the other side of the annular sheath. A cure can be expected

Within a Finger

A finger *should* be in good condition to be worth repair of the tendon. Cicatrix,

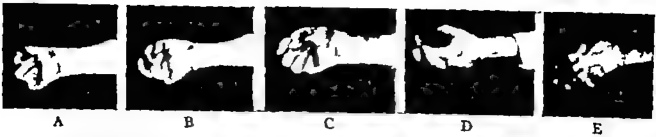


Fig. 372 Case J C. D December 27 1935 an infection from laceration started in the tendon sheath of the right little finger and involved sheaths, spaces, forearm, and wrist joint. The carpals were excised in 13 months, and drainage stopped in 14 months. Seventeen months later all digits were in flexion contracture.

(A and B) Limitations of flexion and extension of digits. The wrist was ankylosed in good position but the flexor tendons of the thumb index, and little fingers had sloughed and the rest were adherent.

Operation (March 9 1938) All tendons were freed. Paratenon from over fascia lata was placed beneath them. New tendons from palmaris longus were supplied to thumb and little finger and another tendon graft to the index finger

(C, D and E) Showing condition eight months later at which time he worked well as a mechanic and also could chop and dig as much, he states, as the other men. The hand opened 3½ inches for grasp. The thumb worked against all fingers. Final report for rating is on p. 76

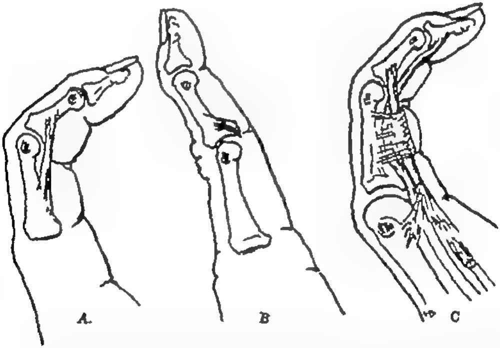


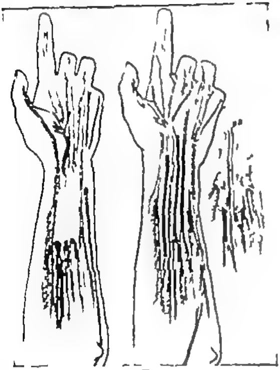
Fig. 3 3 In reconstructing tendons in a finger usually the sublimis tendon must be removed in order to prevent inevitable adhesions between the sublimis and profundus tendons. The sublimis tendon flexes the middle joint and the profundus tendon the distal joint. Therefore, adhesions joining the two tendons will prevent action of the profundus tendon on the distal joint.

(A) If the sublimis tendon is cut off too long the distal end will attach itself to the proximal segment of the finger and draw the middle joint into flexion contracture.

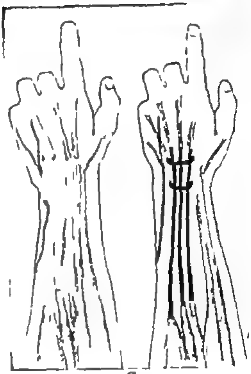
(B) If the sublimis tendon is cut off too short, the middle finger joint will overextend.

(C) If the sublimis tendon is severed in the palm or base of a finger the end of its distal portion will proliferate, attach, and contract producing a flexion contracture of the finger (Courtesy Jour of Bone and Joint Surg., 14 32 1932)

A



B



C

Fig. 374 (A, B C) Case A. T Eighteen months previously a buzz saw almost severed the hand, passing from the base of the little finger diagonally up the forearm, severing most of the tendons and nerves and also amputating some fingers. Infection followed, and in (A) is shown the degree of crippling. The wrist and finger joints are straight and stiff there is no pronation and supination no opposition of the thumb and no sensation except in the area of the radial nerve. There is no power of motion except a slight trace in the thumb The hand is a mere insensitive atrophic club.

Operation (in two stages three months apart) The superficial and deep scar tissue were excised and also the ankylosed head of the ulna, to give him supination, and the wrist was extended By capsulectomy and continuous traction the proximal finger joints were flexed. The remaining tendons were freed and six tendon grafts from the extensors of the toes served to supplant the parts of the other tendons which had sloughed. Two pulleys on the back of the wrist were also grafted in. By flexing all joints and transplanting the ulnar nerve to the front of the elbow the dorsal branch of the ulnar nerve the ulnar nerve, and the median nerve were joined by suture. A sheet of paratenon fat from over the triceps tendon was interposed between the flexor tendons. In (B) and (C) are shown the condition found and the reconstruction done (Courtesy Jour Bone and Joint Surg., 10 14 1928.)

flexion contracture from the median longitudinal incision, or defects in the soft tissue should first be corrected at a preliminary operation One should beware of an annular scar, or even of a scar about the whole volar aspect which severs both volar digital vessels, for the nutrition distally will be poor and perhaps insufficient to maintain postoperatively sufficient vitality for healing Usually, severance or injury of the volar digital nerve on one or both sides accompanies that of the tendons and these nerves should be repaired. The midlateral incision, never anterolateral or median, is used, and often for the length of the finger

Whenever a tendon in a finger or hand is found to be rough, cicatricial, and grossly adherent, it is better to remove it and to replace it with a new one. If the flexor tendons have been severed in a finger in the usual place opposite the proximal phalanx, one cannot join them by suture with success, as the juncture will become adherent in the narrow fixed channel and will not slip It is better to remove the tendons entirely from the finger and graft in a new tendon smooth throughout its length. Suturing is then done in the base of the palm and at the distal phalanx, where adhesions will be of less importance. The tendon of the flexor sublimis to the same finger may be used, withdrawing it through a short transverse incision in the forearm. The palmaris longus tendon plus paratenon usually gives more movement. One flexor

D E F

FIG. 374 (D E F) Case A. T (*Cont*) *Result* (D) (E) and (F) show the hand a year later Sensation is restored throughout, later even including stereognosis. He has 135 of pronation and supination and 78 of motion at the wrist, and the grasp is strong The thenar muscles have regenerated restoring opposition to the thumb. He makes a living as a peddler can button his clothes with this hand, pick up change from his other hand, and, considering his disability has very good function.

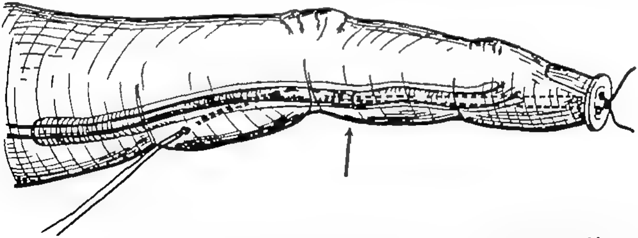


FIG. 375 Repair of the flexor profundus tendon in the middle segment of a finger as either a primary or secondary procedure using removable stainless steel wire. Arrow indicates juncture. Suture is spliced into tendon proximal to juncture to avoid making adhesions at the critical spot. There is good approximation as both tendon ends are threaded on the suture.

tendon in a finger must suffice, for if in our repair we allow two to remain they will become adherent to each other and thus act on the middle joint alone and not on the distal one. Therefore, whenever the profundus tendon is repaired at a primary or occurrence of the latter is observed early, a splint should be used for a while to hold this joint in flexion. If cut off proximal to the proximal joint, the stump will attach to the metacarpal segment and draw both its joints into flexion contracture. This is recognized

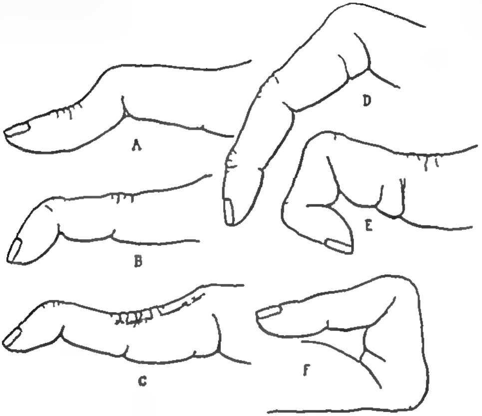


FIG. 376 Causes of the common finger deformities.
(A) Severance of the middle slip of the dorsal aponeurosis.
(B) Rupture of the extensor tendon at the distal joint.
(C) Rupture of the volar ligament of the middle joint or just a double-jointed condition.
(D) Severance of the long extensor tendon at or proximal to the proximal joint.
(E) Clawhand from paralysis of the intrinsic muscles.
(F) Severance of flexor profundus tendon.

secondary operation, if severed anywhere from the distal crease in the palm to the middle crease in the finger, i.e. "no man's land," the sublimis tendon is removed. It is severed opposite the middle finger joint where it is in the form of two flat ribbons one on each side of the profundus tendon. If the stubs from this tendon are left too long they will reach out and attach themselves to the proximal phalanx and produce flexion contracture of the middle joint. If, however they are left too short the middle joint of the finger may hyperextend. If by passively flexing the proximal joint and finding that then the middle joint will extend. Only in primary repairs can a flexor tendon be sutured in the proximal segment of a finger and then only with the most exacting technic, as detailed in Chapter 12.

The usual operation for severance of flexor tendons between the distal palmar and the middle finger crease is to remove the flexor tendons from the finger and graft in the sublimis tendon or palmaris longus plus paratenon, thus prolonging the profundus tendon to the end of the finger. Both junc

tures may be made with removable stainless-steel wire or the proximal one, which is covered by lumbrical, may be of fine silk or fine Fagersta wire and may be left in. A narrow tendon graft will give more movement than a thick one. Excision of the firm annular ligaments with the exception of just enough for pulleys gives better gliding

A late suture of the profundus tendon may be made opposite the middle phalanx, though in a case in which the middle finger joint flexes only partially and weakly, showing involvement of the sublimis tendon also, it is instead usually better to place a whole new tendon graft throughout the finger A profundus tendon severed in the middle segment may snap its vincula and retract into the palm In most cases the vincula holds and the profundus retracts only to opposite the proximal segment, and even late may be drawn down for direct suture This is worth attempting if there is not excessive cicatrix. Some adhesions will result limiting flexion of the distal phalanx. One can, however, later free these and graft some interposing gliding tissue, thus regaining function of the tendon. This graft procedure is frequently necessary after a fracture of the proximal or middle phalanges, or even of the metacarpal.

When a case for repair of a profundus tendon severed proximal to the middle joint shows complete and strong voluntary flexion of the middle joint and none of the distal joint, it is best to refuse tendon operation because our result may not be sufficiently better than what the patient now has. The repair will necessitate the removal of all tendons from the finger and the replacement of a new one, so though the result may be slightly better the procedure is scarcely justifiable. It may however, be advisable to fuse the distal joint in mild flexion in case it does not clutch with resistance.

The flexor tendons occasionally must be held in their beds by reconstructing either the annular ligament opposite the head of the metacarpal, the middle of the proximal phalanx, or rarely of the middle phalanx by the methods already described. Too many pulleys in one finger will, of course, hinder motion

In some situations instead of placing a tendon graft in a digit, the flexor sublimis tendon may be withdrawn from the palm and passed down a shorter digit to use as its flexor Thus, the sublimis of the ring finger may be used to flex the thumb or little finger, that of the long to flex any shorter digit.

For correction of hyperextension of a middle finger joint or a proximal joint in the thumb, a tendon graft is passed transversely through a drill hole in each of the bones and is made to cross like a figure-of-eight over the volar aspect of the joint outside the tendon sheath. It is sutured to itself when the joint is in flexion.

Long Extensor Tendons of Fingers

In the forearm and dorsum of the hand these are quite easy to repair, as the surrounding tissue moves freely Usually the simplest stitch is used, such as a figure-of eight of stainless steel wire through the skin and tendon, and to prevent this fragile juncture from breaking reliance is placed on maintaining the wrist in dorsiflexion and the fingers in extension by adequate splinting. After severance of tendons on the dorsum of the hand, if such splinting is resorted to early, suturing of the tendon is often unnecessary because these tendons do not retract far and readily unite, and also because in the distal third of the hand they interdigitate, one tendon thus moving the adjoining tendons Repair is so easy, however, that to obtain a little better result it is advisable. If the finger drops at its proximal joint to a considerable extent with wrist in dorsiflexion and cannot be voluntarily extended, repair of the tendon is imperative If, however, through the action of the juncturae tendinum it extends well and independently suture will be unnecessary.

If there is cicatrix on the dorsum of the forearm or hand binding the tendons, it will

be necessary to replace it with pedicled skin before the tendons can be repaired By transfer the tendons may be shunted around the cicatrix or a slippery sheet of fascia may be grafted beneath the tendons for gliding For a single tendon sometimes the layer of paratenon that covers the ad joining tendons may be dissected off and folded so it lies under the tendon It is often advisable to excise completely the dorsal carpal ligament to give freedom to the tendons Even though they will bow their motion will be freer If a pedicle skin graft has been applied to the dorsum of the hand, the pedicle may be lifted up, a thin slice of its fat inserted under the tendon and then replaced If the tendons are being joined, they may be passed directly through the fat of the pedicle graft. It is well to be liberal in placing sufficient gliding ma terial under these tendons, using a wide sheet of slippery deep fascia from dorsal or volar aspect of lower part of forearm and fascia of thigh, or else a sheet of paratenon from triceps, outer side of forearm or thigh At the same time one must usually perform capsulectomies on the proximal finger joints On the dorsum of hand or forearm, if the tendons are adherent, the scar tissue may be dissected away and flat strips of stain less steel be placed between the tendons and the deep parts for removal three weeks later The object is to create a synovial lined glid ing plane. One adherent tendon on the dorsum of the hand may hold back the ac tion of the others and need removal, and an adherent tendon here will limit flexion of the proximal finger joint. The extensor proprius tendon of the index or the little finger can be transferred on the dorsum of the hand to do the work of a severed tendon but if used its stub to the index or little finger should be attached to the remaining tendon of that digit, so that the latter will not extend the proximal joint in a rotary manner

Frequently after gunshot wounds through the hand the extensor tendon is adherent or missing and the proximal joint is ankylosed

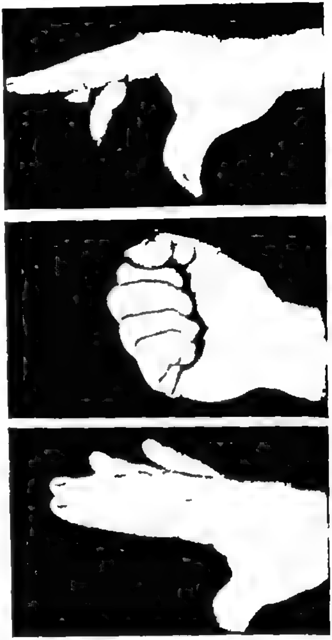
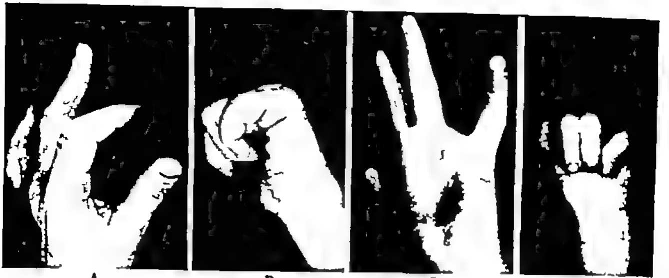


FIG. 377 Case F S.
(*Top*) Drop finger at proximal joint from exploding bottle severing extensor tendon at the joint.
(*Center* and *Bottom*) Simple suture re stored the hand to normal.

It would seem that here arthroplasty and tendon graft must be done in sequence but they may be accomplished at the same time After new pedicle skin has been placed on the dorsum of the hand, a tendon graft may be passed through its fat and arthroplasty may be done at the same operation. The wrist is put up in dorsiflexion and the prox imal finger joints straight. After a week when the danger of blood clot between the bones is over, longitudinal traction is ap-



A B C D

FIG. 378 Case C. B A buzz saw amputated the ring finger and severed the extensor tendons of the three remaining fingers in their proximal segments. In (A) is seen the resulting limitation of power of extension. The difference in the positions of the index and long fingers is due to the severance in the long finger of only the central portion of the tendon allowing lateral portions to pull around the middle joint and extend the distal joint. In (B) is shown the lack of flexion as checked by the extensor tendons which are adherent in the scars.

Operation The scars across the backs of the fingers were excised and the severed ends of the extensor tendons were freed of scar tissue and sutured together The extensor tendon of the index finger was so adherent that a free graft was made sheath-like about it for its full length in the finger from the specialized paratenon fat from over the triceps tendon. Later as the fingers still could not be flexed completely the flexor tendons of the amputated ring finger were removed from the palm. They had become adherent to the stump and so prevented the rest of the flexor tendons from being pulled upon by the flexor muscle. Normal function was restored to the hand, as shown in (C) and (D) (Courtesy Surg., Gynec., and Obstet., 39 268 Sept., 1924)

plied to the finger, and after the third week when the tendon has united the proximal finger joint is drawn into flexion

While repairing metacarpals after gun shot wounds the extensor tendons may be repaired at the same time placing a layer of gliding material beneath them doing a capsulectomy and dorsiflexing the wrist to slacken the tendons.

For repair of the tendons on the dorsum of the finger the reader is referred to Chapter 10, Intrinsic Muscles of the Hand.

Thumb Tendons

Extensor Pollicis Longus. This tendon draws the thumb backward behind a plane with the dorsum of the hand and by it, when all other actions of the thumb are gone, the thumb can pinch against the side of the hand. In the sweep of the thumb in the motion of opposition this tendon aids in coordinating with the other muscles. If it becomes adherent on the dorsum of the wrist it will check the motion of opposition. Severance of this tendon results in partial inability to extend the proximal joint of the thumb and complete inability to extend the distal joint. If the extensor pollicis brevis tendon is also severed, the proximal joint of the thumb will drop completely The extensor pollicis longus tendon is frequently ruptured at or following a Colles' fracture or from a blow on the dorsum of the lower end of the radius against the bone or its bony ridge Here also is a common site for severance by laceration. This tendon in older people often ruptures from excessive wear in passing through the bony groove in the radius. It is then known as drummer's palsy, but also occurs in other workers, such as polishers, waiters, and woodcarvers. Following Colles' fracture 71 cases have been reported. The average time from the fracture being six weeks, it is prob-

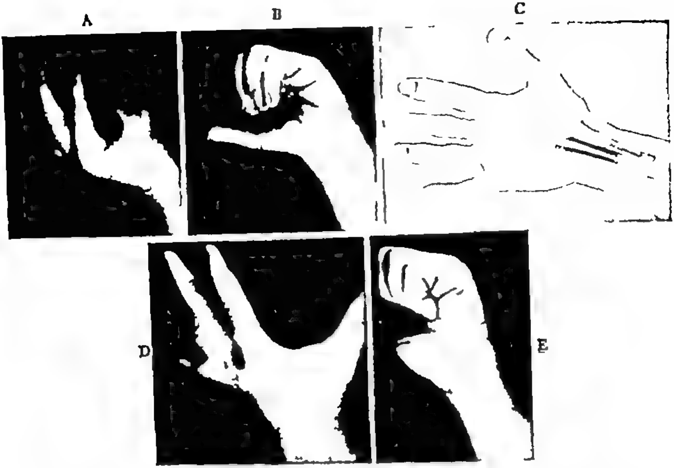


Fig. 379 Case E. L. E. Two months previously an ax flew off its handle and severed the extensor tendons of the index and long fingers and the extensor carpi radialis brevis. Infection followed leaving the rest of the dorsal tendons bound in scar tissue. Extension of the fingers was much limited as shown in (A) and flexion was prevented by the attachment of the extensor tendons in the scar as shown in (B)

Operation The scar was excised and all of the extensor tendons of the wrist and fingers were dissected from the dense scar tissue. The severed extensor carpi radialis brevis was sutured together Between the severed ends of the extensor tendon to the index and long fingers was a gap of 1½ inches due to sloughing of the tendon ends. These two gaps were bridged with free tendon grafts from the palmaris longus, with its paratenon fat about it as in (C) The function four months later is shown in (D) and (E) (Courtesy Surg., Gynec., and Obstet., 39 267 Sept., 1924.)

ably due to partial injury and then wear on the new contour of the bone.

Repair of this tendon is quite successful. If the severance is clean-cut it can be done by suture, but usually a short tendon graft from the palmaris longus is necessary Another simple method of repair is to transfer to it the tendon of the extensor digitorum communis to the index finger, or that of the extensor indicis proprius. In either case, the stub of the tendon left at the knuckle of the index finger should be imbedded into the adjoining tendon of that finger to prevent a rotary pull The splint used after repair of this tendon should hold the wrist in dorsiflexion and the thumb in extension. This can be done with plaster of Paris or by a cock up splint with a metal extension from its neck to hold the thumb fully extended

Extensor Pollicis Brevis. This tendon in itself is unimportant, though it is most useful as a transfer for opposition of the thumb or for the cross member of the tendon T operation Rarely is it absent or it may extend the distal joint as phylogenetically it is new being found only in the gorilla and man

Abductor Pollicis Longus. This strong tendon holds the carpometacarpal joint in extension and so is a very important stabilizer at the base of the thumb W

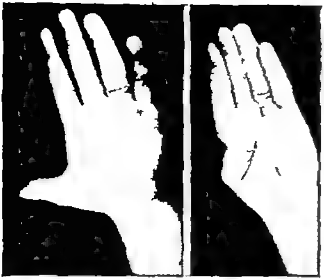


FIG. 380 Case F S., aged 16 Two months previously he severed with a saw over the metacarpal the tendon of the extensor pollicis longus and brevis. Retraction was only an inch so repair was by simple suture. The result is shown in the two illustrations above.

it the thumb is useless. On attempts to pinch between the thumb and index finger the metacarpophalangeal joint drops into extension, breaking the arch of the thumb, and the whole thenar eminence rides forward in the palm, the thenar crease bending at a right angle. The fingers may grasp against the back of the flexed thumb The tendon is readily repaired by suture or graft and is not likely to become adherent. Its amplitude of motion is short, being about half that of the tendon of the extensor pollicis longus, so that another tendon transferred to both of these two cannot move the extensor pollicis longus tendon through its complete range It may readily be reactivated by restoring its own continuity or by attaching to it a slip split up from either the extensor carpi radialis longus or the flexor carpi radialis Another alternative is to attach to it the palmaris longus Attention is frequently drawn to the tendon of the abductor pollicis longus by the presence of local pain, due to either stenosing tenovaginitis or to an adjoining aberrant tendon of the thumb

Stenosing Tenosynovitis at Radiostyloid Process (de Quervain's Disease) Disability from thickening of tendon and tendon sheath with constriction of the tendon is well known as trigger finger and trigger thumb, and has been seen in the tendon of the extensor pollicis longus, extensors carpi radialis, extensor carpi ulnaris, and peroneus longus. De Quervain in 1895 first described the condition in the abductor pollicis longus tendon over the lower end of the radius. Since then over 200 cases of the latter have been reported

ETIOLOGY The tendon of the abductor pollicis longus, accompanied by that of the extensor pollicis brevis, runs through a ligamentous synovial lined sheath for 1¼ inches over the prominence of the radiostyloid Here it runs in a shallow bony groove, where it is subject to direct trauma. At the styloid process this tendon is subject to an unusual degree of sharp angulation in the various motions of the wrist.

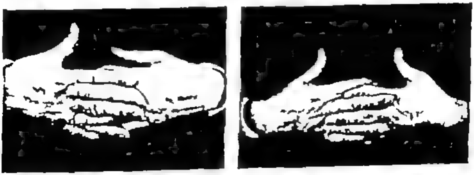


FIG. 381 Case H. E. C
(*Left*) Inability to extend left thumb due to severance of tendon of extensor pollicis longus at the wrist with the knife six months previously
(*Right*) Repair was made by a 3½ inch tendon graft from the palmaris longus.

ecause of the angulatory motion of the vicular the thenar eminence moves on the earm much more than does the hypoth ar, and this exaggerates the angulation the tendon as it passes from radius to first etacarpal so that in many of these cases e angle equals 105° The joints in women gulate farther than in men suggesting n explanation for the preponderance of ese cases in women ; Evidently it is the iction between the tendon, tendon sheaths, id bony prominence incurred in holding ie tendon in its bed, through its great nge of angulation that results in tenoynovitis which eventually becomes stenosig As expected, it is most frequent in ianual workers, particularly those who inch with the thumb while moving the rist. The abductor pollicis longus is a trong stabilizer essential for a hard pinch ith the thumb Though in the majority f cases the onset is gradual, in many it tarts acutely following a blow or sudden train of gripping or lifting, or may follow hard day s work of typewriting, piano laying twisting a drill, drafting or gripping books.

SYMPTOMS From the onset whether gradual or acute, the symptoms persist and may not be relieved by splinting. The main complaint is of aching one half inch above the styloid tip and radiating down the hand and up the arm to the shoulder This is increased by use of the hand and especially by motions of the wrist and thumb When the thumb is strained in extension against resistance, and especially when the wrist is dorsiflexed, flexed or abducted so that the tendon pulls on the sheath at an angle, pain is produced and is exaggerated by local digital pressure Tenderness and swelling are present along the tendon from one to 2½ inches. Motions of the wrist and thumb may be normal or slightly limited. There is complaint of weakness of the thumb and actual diminution of grip Occasionally a nodule can be felt at the site of pain which may move

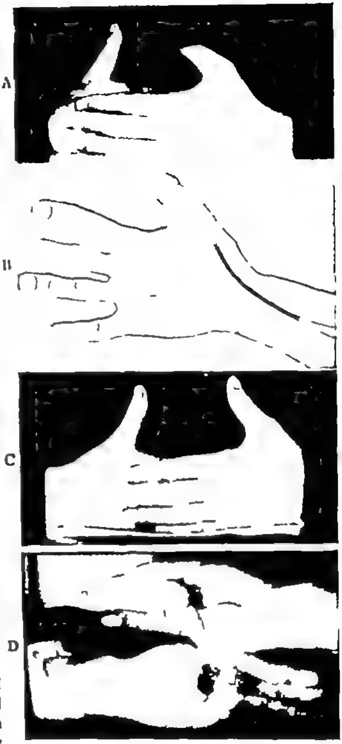


FIG. 382 Case E L J Three months previously the tendon of the extensor longus pollicis was severed in a laceration from a broken bottle across the dorsum of the wrist. An infection resulted and about 2 5 inches of the above tendon sloughed out. The resulting inability to extend the thumb is shown in (A)

Operation A 2.5 inch length of the palmaris longus tendon was used as a free graft as in diagram (B) The resulting function three months later is shown in (C) and (D) (Courtesy Surg., Gynec., and Obstet 39 268 Sept. 1924)

somewhat with the tendon Crepitation is not common.

PATHOLOGY In mild cases the pathology, though present, may be inconspicuous, but in severe ones it is quite marked On exposing the outer surface of the sheath one may notice reddening from increased vascularity, and some edema over a distance of about one inch opposite the prominence of the lower end of the radius It is well before opening to insert a small probe in the tendon sheath from above and also from below to locate the region of the stricture which is usually present.

On opening the sheath the synovial fluid occasionally is increased and may be yellowish Spiderweb-like adhesions may extend between the tendon and the sheath for

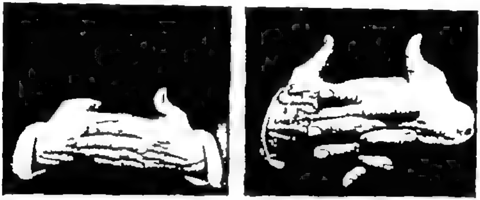


FIG. 383 Case T L. B

(*Left*) Loss of extension of thumb from rupture of three years standing of tendon of extensor pollicis longus on a spicule of bone three months following a Colles s fracture.

(*Right*) Extension was restored by transferring the tendon of the extensor digitorum communis from the base of the index finger to the distal portion of the extensor tendon to the thumb The tendon stump of the extensor communis was sutured to the extensor indicis proprius to prevent rotary deformity

FIG. 384 Case R. R. With a knife three months previously the tendon of the abductor longus pollicis was severed.

(*Left*) The thenar eminence rides forward. The thumb is drawn backward on spreading by its long extensor and lacks ½ inch of full extension measured at its tip.

(*Center*) In pinching the arch of the thumb is lost as the metacarpophalangeal joint drops from lack of the abductor thus making a poor O and a weak pinch.

(*Right*) At operation the tendon had retracted so far that it was necessary to use a three inch graft of two-ply palmaris longus to bridge the gap. The graft and corrected position of the thenar eminence show clearly in photograph.

one half to one inch The ligamentous sheath which normally is about three fourths of a millimeter in thickness may be from two to four times as thick The tendon and sheath may be less lustrous and over the tendon itself the epitenon is inflam matory, ranging from slight edema to a red dish or brownish congested, scum like, lusterless covering of the tendon for one-half inch or more. Rarely does the tendon show a constriction and bulbous enlarge ment above and below In exploring these under local anesthesia one notices that the tendon and sheath where inflamed are ex tremely sensitive. Microscopically they are thickened and vascular and show cellular infiltration and some cartilaginous changes especially of the ligamentous layer The synovia may be eroded in places. There is a close analogy in the cause and findings to traumatic arthritis.

TREATMENT Conservative treatment consists of immobilizing the tendon in a nonpadded half cast of plaster of Paris, in cluding the volar two-thirds of the forearm, the palm, and the thumb to its distal crease. The wrist should be in slight dorsiflexion and the thumb in its normal position If a cure or considerable improvement is not obtained in a month, operation is indicated

It is not necessary, just because the ten don runs longitudinally, to make the customary longitudinal incision, which so often forms a conspicuous scar or even a keloid A short transverse incision will suffice, and later becomes invisible As soon as the skin is cut it should be undermined upward and downward for the required distance. A longitudinal incision should then be made through the superficial fascia from above downward so as not to injure any twig of the superficial radial nerve. The branches of this nerve diverge from each other in the deep part of the superficial fascia. On re tracting this layer the tendon sheath is in spected Through a small opening above and one below palpation for constriction is made with a thin probe. The sheath is then slit open for its length and left so If a third tendon is found within the sheath it should be removed Most writers on the subject report uniform cures, though some

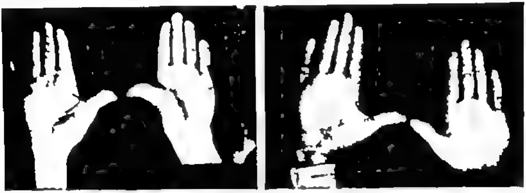


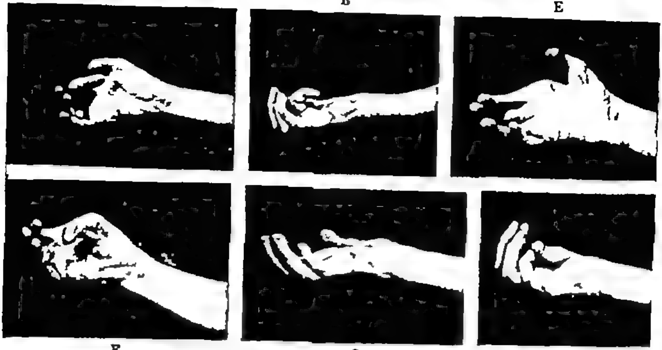
FIG. 385 Case C. M. S

(*Left*) Six months previously the two short extensor tendons of the thumb and the radial nerve were severed by a knife. Considerable disability of the hand resulted, in that the thenar eminence rode forward. Abduction of the thumb was limited one-half inch and the thumb lost much of its function. He grasped either without the thumb or on the dorsal surface of the flexed thumb The pinch of the thumb was weak, in that the arch of the thumb was gone. As the metacarpal lacked extension the metacarpophalangeal joint dropped for ward in pinching.

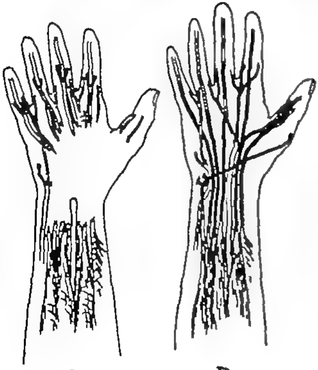
The radial nerve was sutured and as the muscles had retracted a two-inch tendon graft from the palmaris longus, plus its paratenon, was used to bridge each of the short extensor tendons of the thumb

(*Right*) In three months sensation returned and he had normal function of the thumb (Courtesy Bone and Joint Surg 10 6 1928)

A B E



F G H



C D

FIG. 386 Infection entering the tendon *sheath at the pulp of the thumb* extended down the little finger through the radial and ulnar bursae and midpalmar and thenar spaces, sloughing out all tendons and the median nerve. For five weeks it had been draining through a few tiny "medical" incisions before it was drained widely

(A and B) *Showing limits of flexion and ex tension and the completely disabled condition of the hand a year later*

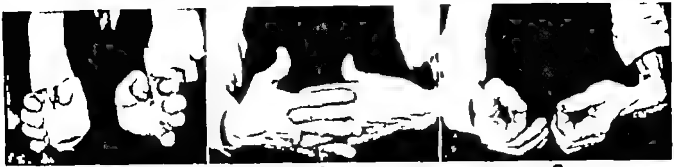
(C and D) *Operation.* The scar tissue was dissected out from the palm and first interdigital cleft. It was found, as in C, that all tendons and the median nerve and its branches had *sloughed from above the wrist to the distal* part of the palm. The index finger extended on releasing its tendon stump.

A tubular pedicle from the abdomen was laid in the palm, to the wrist on the thumb and through the thumb cleft.

Four months later the median nerve was freed *to elbow drawn down flexing the elbow* and anchored in the palm.

Four months later the median nerve was sutured to its five branches. Flexor tendons were removed from the index finger replacing them by the opposite palmaris longus, suturing to the tendon in the forearm. New tendons from ex tensors of toes were grafted for the other four digits as in (D) and a pulley operation was done *to furnish opposition to the thumb using a flexor sublimis,* the tendon of the flexor pollicis brevis and grafting a pulley An arthroplasty was done on the proximal joint of the little finger

(E F G and H) *Showing the degree of motion obtained The thumb opposes to two inches in* front of the base of the long finger Sensation returned throughout in nine months. She holds three of the examiner's fingers firmly and has considerable use of the hand, *readily doing her housework.*



A B C

Fig. 387 Case O. V. J. Deformity from severance of the thumb stabilizer, the tendon of the abductor pollicis longus, left hand.
(A) Thenar eminence rides forward. Note the thenar crease.
(B) Extension of thumb is limited in the carpometacarpal joint.
(C) Pinch against the index finger is weak and makes an ellipse instead of a good O, as the carpometacarpal joint cannot be stabilized in extension to give a good arch of the thumb.

whose cures have not been complete argue for not only slitting the sheath but for excision of it. It is possible that failure to obtain complete relief in these cases has been due to the presence of an aberrant tendon.

Aberrant Tendon of Thumb. Of 22 personal cases operated upon, which came because of symptoms of de Quervain's disease, in 12 an aberrant or third tendon within the tendon sheath was found. Various anatomies state that occasionally the tendon of the abductor pollicis longus sends a slip of insertion to the thenar fascia or the trapezium, but apparently a third tendon in the sheath is a rarity; still, in 12 out of 22 cases this was found. In a recent case five tendons were found, one of which to the scaphoid showed hour glass constriction.

In four of these there was some inflammatory thickening of the epitenon and in one some thickening of the tendon sheath. In the remaining seven the aberrant tendon was the only unusual finding. In all ten of those cases without an aberrant tendon there was seen some of the usual pathology of de Quervain's disease. Most of the 12 aberrant tendons had a separate muscle slip which fused higher into the muscle of the abductor pollicis longus. In one, the tendon forked at the tendon muscle juncture and in one case it was bilateral. The tendons were one to 1½ inches long and lay along the volar aspect of the tendon of the abductor. None of them inserted into the

Fig. 388 Case M. B. The flexor pollicis longus was severed by a knife-puncture wound through the thenar eminence ten days previously.
(*Left*) The scar and loss of flexion of the distal joint of the thumb are shown.
The tendon was recovered at the base of the thenar eminence and was fastened to its distal end by a removable stainless-steel wire suture which passed on down the thumb to be fastened outside the skin to a button.
(*Center* and *Right*) Taken six months later showing complete recovery.

FIG. 392 Case H. B The right hand and wrist were caught under a cave-in the dorsum of the wrist and a distance up the forearm becoming gangrenous. The extensor tendons to digits and the extensor ulnaris sloughed, and as the head of the ulna was exposed the wrist joint became infected.

The head of the ulna was excised and after severing the tendon of the flexor ulnaris the wrist was drained widely open. All healed in two months.

(*Left*) Preoperative condition.

Operation (*1*) After excising the 3½ by 1¼ inch cicatrix a flap of skin from the dorsum was swung to cover the area and the part left denuded on the radial side was covered by skin graft. The tendon of the flexor ulnaris was seen to be reunited.

Operation (*2*) Three months later New tendons were supplied to the fingers by five-inch grafts of fascia lata, joining the muscles to the tendons at the center of the dorsum of the hand, and one to the extensor carpi ulnaris.

(*Center* and *Right*) Taken four months later showing good function of the fingers. The wrist has 30 of motion and there is full pronation and supination Adduction is strong. He works steadily

the tendon sheath opposite the head of the metacarpal, due to the trauma of gripping *The condition is easily remedied by making* two cuts, one through each side of this annular ligament. On cut surface one will see a thickened annular band at about the center of this sheath several millimeters wide and 1½ mm thick The flexor tendon opposite this band will be seen to be narrowed, and distal to it the tendon will be bulging sometimes for the distance of a centimeter and to twice its normal diameter

POSTOPERATIVE TREATMENT AFTER REPAIR OF TENDONS

Postoperatively the repaired tendons should be protected from breaking by splinting for three weeks and partially so for four weeks. For the flexor tendons the wrist is held in flexion but the digits are free, and for the extensor tendons the wrist is held in dorsiflexion and the involved digits in extension. If after repair of flexor tendons the fingers are splinted in flexion, the tendons will adhere so far proximally that the fingers cannot be extended Flexion of the wrist, alone, robs the muscles of strength enough to break the tendons and allows some motion of fingers and tendons.

We should prevent accumulation of edema, serofibrous exudate and hematoma by placing tiny rubber tube drains for 24 hours if there is much oozing surface by immobilization by splinting by a pressure dressing, and by elevation. Unless we do the above, excess of adhesions will form which will limit the movement of tendons and joints. *On the following day all constricting circular bandages or dressings are* slit through to allow for swelling and to prevent dangerous ischemia which leads to necrosis, and drains are removed lest they encourage infection. Moderate pressure by bandaging is then reestablished Any digits which do not need splinting are left free to move so as to prevent stiffness. The limb should be kept elevated for a few days to limit swelling.

Exercise following the repair of tendons need not be started early The patient, because of pain, will not exercise until after the first week or two, and also he should not do so because exercise interferes with the early healing which should be as reactionless as possible. It so irritates the tissues involved in the repair that excessive tissue reaction occurs, resulting in overhealing followed by binding adhesions. Also, free

tendon grafts should be given the opportunity to establish a new blood supply before subjecting them to movement. Only a very little weak motion is allowed for the first two or three weeks By the end of three weeks the skin incisions will be healed enough so they will not break on flexing the fingers palm, or wrist and the tendon ends will be physiologically united enough for moderate exercise At this time, the stainless steel wire sutures are removed, leaving the tendons free from irritation and released for exercise

At this stage, the tendons not exercised will be found to be less adherent in their beds than are those which were exercised Some protection by splinting should be continued until the end of the fourth postoperative week, though during the third week the angulation of the splint can be eased up a little, to give a little more chance for movement but still to protect. Commencing at the end of the third week movements should be encouraged. They should be guarded and without strength during the fourth week, but after that the danger of breaking is over and the tendons may be exercised with increasing force.

Of late we have been inclining toward very mild graded movements and commencing on the first postoperative day Sutures when placed are tested to be sure they will hold In some intelligent and cooperative patients the wrist splint also may be removed on that day The finger is exercised frequently but without force until after three weeks Then moderate force is used for the succeeding week and from then on vigorous force

To make a flexor tendon move through the finger the patient should first hold with his other hand his proximal finger joint in extension and then make the muscle contract. This will pull the piston through the cylinder and flex the middle joint. To make the tendon pull through the middle segment of the finger he should hold in extension both the proximal and the middle joints while he pulls on the tendon. Meantime, the joints themselves can be made to flex passively while the tendon is pulling Gripping on a rubber ball does not make the tendon glide through the finger, as only the proximal finger joints move It is better to grip on the rounded edge of a flat block of wood one half inch in thickness, 2½ inches in breadth, and 3¼ inches in length The piece is gripped crosswise to exercise the middle joints and lengthwise for the distal joints The narrow, rounded edge furnishes a good fulcrum over which the joints can bend

The best results are obtained by patients who after the first month exercise vigorously and often, even in spite of discomfort or pain One must carry on in spite of these for the reward of a good result. Exercise of the hand is best done after it is heated up by immersion in warm water Soap added to the water lubricates and softens the skin and aids in working one hand with the other Merely flexing the fingers passively by the other hand does not exercise the tendons as well as in flexing the fingers on their own power while their proximal joints are held in extension. Flexing a finger, and at the same time compressing its volar aspect, causes a flexor tendon to project one inch into the palm. Extending a finger passively drags that tendon distalward through the finger The hand may clutch warm sand in a bag kept on a radiator, and if this wears the fingers rice may be used Bouncing putty, a by-product of General Electric Company, has an excellent consistency for gripping Rubber sponges are better to work on than are rubber balls Should a patient, because of fear of pain refuse to flex his fingers so as to loosen the repaired tendons he may be made to do so after first blocking with novocaine his median or ulnar nerve in the forearm

It is necessary during the third to fifth weeks to have the patient report two or three times weekly, so as to instruct him in these exercises, for it is usually found that *it takes* at least three instructions before he grasps the principles and retains

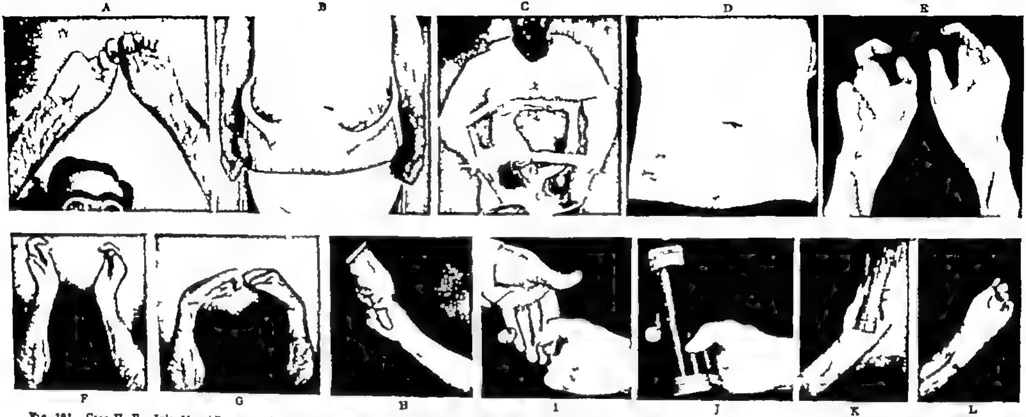


Fig. 391. Case H. F., July 31, while on a pole, to prevent falling he grasped two wires carrying 2,300 volts. In the subsequent six months all of the flexor tendons and the median and ulnar nerves sloughed out from each palm and wrist, leaving both hands totally disabled.

(A) The volar aspect of each hand is anesthetic, cicatricial, and with flexion contracture. T exist he needs a valet.

The cicatrix was excised from each and after replacing it with good pedicle skin nutrition returned to the hands and good range of motion to the wrists.

(B, C, and D) Showing two pedicles prepared, applied to the hands, and the resulting scars.

(E) Showing the new skin in place and the general loosening effect on the hand restoring nutrition.

(F and G) Showing motion restored to wrists which had been fixed in flexion. An extensive operation was done on each hand and several subsequent ones.

Right Hand. The cicatricial remnants of all flexor tendons were removed and replaced by free tendon grafts from the long extensors of the toes, suturing to the distal phalanges of the thumb and index finger and to muscle masses up the forearm. A pulley operation was done to give opposition to the thumb and a tendon T operation to give it adduction and to restore curvature of the arches. Graft material for this was taken from the extensor tendons of the amputated fingers, and that from one of these was transferred to the tendon *of the first interosseus muscle* to give abduction to the index finger

The dorsal branch of the ulna nerve wa saved by stripping it well up the nerve nd the main nerve wa opened out and used as a 7½-inch graft to join the median nerve to its three branches.

Later a rotary osteotomy was done on the metacarpal of the thumb to make it oppose the index finger

Left Hand. A third tubular pedicle was prepared and from it good skin replaced the cicatricial ends of two finger stumps and the volar part of the thumb.

A capsulectomy was don on the proximal joint of the little finger The extensor tendon f the amputated long finger was transferred to the tendon of the first interosseus muscle to bduct the index finger

Four free tendon grafts from the other foot were used to connect the muscle masses in the forearm to the last phalanx of the thumb, index, and the two finger stumps.

A pulley operation was done to give opposition to the thumb and also a tendon T operation to give it adduction and to give curvature to the arches. Both median and ulnar nerves had sloughed. *Therefore, grafts from the sural nerves were used—three-ply for the* median and two-ply for the ulnar—as five-inch grafts to connect them to their branches including the motor branch of the ulnar nerve. All tendon sutures were done with removable stainless-steel wire.

(H, I, J K, and L) Showing that he now has much use of each hand. He no longer needs someone to take care of him, but can eat, dress, and d many things without help. H writes well and holds firmly in either hand from one to four of the examiner's fingers. Each index finger abducts strongly Sensation has returned throughout the *right* hand and in the left, which was done only recently to as f r as the bases of the digits.

Though he *will not do manual work,* he *is now self-sufficient and will make* hi own living in the electrical line.

them Exercise and work with the hands must be persisted in for many months

A patient's own voluntary exercise and work with his hands throughout all the hours he is awake are of far greater benefit to him than spending an hour a day in a physiotherapy department, with the superstition of bubble baths, magic lights, and traumatic manipulations. Rough manipulations produce microscopic tears and hemorrhages throughout the restraining tissues, which are followed by reactive cicatricial healing, thus increasing the stiffening Our early impressions, still widely prevalent, that we can make a rusty hinge work if we move it enough or a stiff piece of leather mobile if we work it sufficiently should be discarded when dealing with live tissue with its sensitive reaction to trauma Commencing in the fourth postoperative week occupational therapy is most beneficial (see Chapter 7)

It will be found that after tendon repair voluntary motion becomes less in the first two weeks, at the end of which time, due to adhesions, there will be the least motion. From then on the tendon gradually loosens from its surroundings so that by the end of a month there is a fair amount of motion, though it is still considerably limited From this time on the motion will gradually increase in response to use For a number of months there will be some induration along the tendon in the forearm or in the palm, which will bind the tendon A tendon will not move to its normal amplitude through such an area until complete softening has occurred Measurements from month to month will show a continued increase in range of motion for a year or more. Often at the end of eight months increased motion occurs.

In some cases the progress in motion seems to stop, and in these when one then uncovers the tendon one will find that tendon or surrounding paratenon may have reached out from the side and attached itself to surrounding firm, immobile tissue, thus preventing excursion This frequently takes place when a juncture is in the distal part of the palm, where fascial septa and fascial annular tendon sheaths have a special affinity for these attachments From such a point distally the tendon will be bound to be attached, but to a lighter degree In cases which do not show sufficient movement after many months have elapsed it is often worth while to reoperate, excise adhesions, interpose gliding material (paratenon or the smooth surface of deep fascia) between the tendon and its attachment, and then to start motion early

EVALUATION OF RESULTS AFTER TENDON REPAIR

If one attempts to estimate results by statistics, too many variables are encountered for a satisfactory tabulation There are too great differences in the conditions of the different hands, such as magnitude of injury, number of tendons, and other structures repaired, accompanying months of nerve injury, state of nutrition, amount of cicatrix, type of person, and what procedures were used—graft, suture transfer, or freeing A rough conception based on estimations from experience, is probably as accurate and as practically useful.

In tendon repair we can expect good results if the tissues approach the normal in quality and poor results if they are cicatricial and the state of nutrition low Lack of nerve function is detrimental to tendon and joint repair There is a better chance for good motion if only one tendon is repaired than if the whole set is replaced by tendon grafts and other procedures are done, because the general reaction and amount of cicatrix is less People who understand and will exercise in spite of pain will be rewarded by better results The cicatricial index of each individual is a big controlling factor In some the joints and tendons remain mobile even in spite of considerable trauma, while in others moderate

inflammatory reaction combined with immobility results in stiffness

In very few isolated instances is there less motion afterward than before repairing the hand and then only if hematoma or infection follows the repair Most hands are made materially better and show much more movement after tendon repair Only from experience does one learn which case not to tackle and what to attempt with reasonable chance of success, guided always by an estimate of not only the practical benefit to be gained, but in addition the ultimate satisfaction to patient, insurance company, and surgeon. The old adage about making a silk purse out of a sow's ear is here quite apropos.

If the tissues are soft, pliable, and fairly normal, tendon repair should yield excellent results, providing that it is done in conformance with the many principles and tiny details, and with the correct technic. Often tendon grafts give perfect results, though usually under critical judgment the measurements of motion will lack a little of the normal If the tissues are cicatricial and the nutrition lowered the amplitude of excursion of the repaired tendons will be proportionately less.

Certain tendons give better results after repair than others thus, we may expect perfect success in the repair of the tendons that move the wrist, and in that of the extensor pollicis longus and abductor pollicis longus. Next in good results come the extensors and flexors of the fingers repaired in the forearm, the digital extensors on the dorsum of the hand. A result in these that can be considered perfect is seen only when, at the same time in the case of flexors, the wrist and fingers can be fully flexed, or after the repair of extensors the wrist be fully dorsiflexed and the digits simultaneously extended. Many cases can pass this test and many with more cicatrix cannot but will have sufficient motion for excellent function.

Tendon repairs in the palm come next in order of success Extensors and flexors within a finger are the most difficult to repair The most difficult of all are the flexor tendons from the proximal end of the annular tendon sheath over the metacarpal head to just past the middle joint in the finger, where they pass through the narrow, firm tunnel. Though primary suture can be accomplished successfully here, in secondary repair a free graft is necessary This is a common operation, substituting as a graft the sublimis or preferably the palmaris longus plus its paratenon for the profundus tendon, and the usual result obtained when there is only moderate cicatrix present is voluntary flexion to or near the base of the palm Only sometimes does the finger flex to the distal crease in the palm, though never with the final clench there as supplied by the flexor sublimis tendon. In the average case in full flexion the proximal joint is normal, the middle joint usually flexes to a right angle, and the distal joint may not flex when the finger as a whole is flexed. If, though, the distal joint is tested individually by holding the middle segment of the finger, or by gripping about an object, the distal joint flexes to about 40° Auchincloss wrote of "that beckoning call of the terminal phalanx." From this, which can be considered a good result, there are many more cicatricial fingers in which the flexion after grafting a new tendon in them is to only two-thirds or one-half the normal This degree, however, will be useful, but when a finger stands too much out in the way it is better amputated

A sutured or grafted tendon may gain its usual amplitude of excursion, but usually it falls a little short of the normal in both extension and flexion, that is, at the two extremes of its range of motion. The more factors against obtaining a good result, such as extensive cicatrix, poor nutrition lack of nerve supply and the total amount of crippling, the less we can expect of the repaired tendons in amplitude of motion.

In extensive cases in which a full set of

tendons and nerves is supplied to the hand by grafting, and even sometimes in the extensor aspect as well as the volar, we can usually expect return of sensation, sufficient extension of the digits for grasp—such as two to three inches between the thumb and fingers—and the ability to hold objects firmly, ranging from this size to tiny ones between the thumb and fingers Even this, however, means much to the patient who had total disability of his hand

Thus, in some cases with little cicatrix and only a few tendons injured the eventual result after tendon repair is equal to or near the normal, but with increase of the factors against us, as just mentioned, the results that can be expected are proportionately in accordance.

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10

Intrinsic Muscles of the Hand Loss of the Thumb Methods of Repairing

INTRINSIC MUSCLES OF FINGERS
INTRINSIC MUSCLES OF THUMB
LOSS OF THUMB, METHODS OF REPAIRING

INTRINSIC MUSCLES OF FINGERS

With the progress of surgery certain finer aspects, which only a few decades ago would have seemed unimportant, are now essential.

The intrinsic muscles of the hand, though tiny, are important because, with the long extensors and long flexors, they complete the muscle balance in the hand. Normal position, normal motion, and even strength of the grip of the hand are dependent on this nice balance of these three sets of muscles

With loss of action of the intrinsic muscles the thumb cannot oppose or adduct. It lies to the side of the hand The carpal and metacarpal arches are flat and the fingers are clawed. They cannot simultaneously flex in their proximal joints and extend in their distal two joints, and are practically devoid of lateral motion. The hand has lost its skill and finer movements

In hands not suitable for nerve repair, much of this imbalance can be corrected surgically by tendon transfers Cases include those of ulnar nerve paralysis and those of paralysis of ulnar and median nerves. Also included are those with loss of intrinsic muscle action of one or several digits. The correction of these has been found worth while in improving the function of the hand It is possible, if the tissues are sufficiently flexible, to restore opposition and adduction of the thumb, curvature of the carpal and metacarpal arches, some lateral motion of the fingers, and the ability to flex their proximal and extend their distal two joints simultaneously The phylogeny of these muscles may be found in *Chapter 1*

Anatomy and Function of Intrinsic Muscles

In the literature regarding the function of the intrinsic muscles controlling the fingers, one finds such a wide divergence of opinion that it is evident that the subject is still in the controversial stage. Textbooks of anatomy largely agree but are incomplete as they fail to consider synergic action between the muscles, stabilization and coordination, and the conception that the lumbricales and interossei have a different action when the proximal finger joints are in their first half (45°) of flexion than when they are in their second half, and a different function, depending on whether or not the extensor tendon stabilizes the proximal finger joints in extension.

Embalmed cadavera are worthless for this study when compared with fresh hands Recent advances are to be found in the contributions of *Montant* and Baumann, Hauck, Mason, *Salisbury*, and Hopper In collaboration with *L D* Howard, Jr, and Donald R. Pratt, the author has dissected fresh cadavera, and made observations in

the living during operations on the hands. He also has made direct examinations of normal and crippled hands in movement. After reviewing all available sources, the following conception of the anatomy and function has been reached.

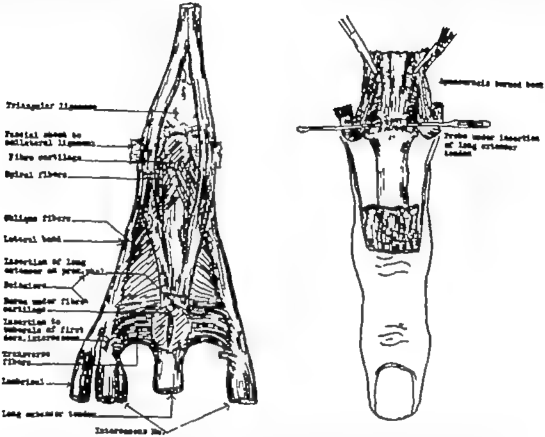


FIG. 394 (*Left*) View of the under surface of the dorsal aponeurosis of the right index finger This complicated aponeurosis coordinates the muscle action of the long extensor the interossei, and the lumbricales.
(*Right*) The *dossière* ("cloth over the back of a throne") is turned back to show the insertion in the proximal phalanx of the long extensor (Courtesy Jour Bone and Joint Surg., 24 8 Jan. 1942)

Dorsal Aponeurosis or Extensor Assembly The thin sliding dorsal aponeurosis of a finger is a complicated mechanism which makes for ingenious coordination in action of the long extensors and flexors, and the lumbricales and interossei, so that the complete motion of flexion and extension of a finger is smoothly carried out various muscles take over the action in turn, although each individual muscle has but a limited excursion of motion By relaying the complete motion is carried out, first by long extensors then intrinsics

The tendons of the interossei and more laterally of the lumbricales *fuse into the* sides of this aponeurosis where they can be readily palpated in the finger They first give off fibers transversely, as a sling over the dorsum of the proximal phalanx, *for* flexion of the proximal finger joint, and then continue on as the lateral band on each side of the finger to divide, the median fibers extending the middle joint and the lateral ones the distal.

The long extensor tendon, as it spreads into the aponeurosis, gives off first a central deep ribbon from its under surface to extend the proximal finger joint, and then divides into three slips—the central one for the middle joint and the two lateral ones fusing with the lateral bands to extend the distal joint. Kaplan found the deep ribbon to be present in only 38.5 per cent and that the capsule acted to extend the joint.

Over each of the joints the aponeurosis is thickened to a small disk of fibrocartilage, the proximal one of which overrides a bursa which separates it from the joint capsule. Only the distal two of them are inseparable from the joint capsule.

Shift of Aponeurotic Sleeve At the base of the finger there is a remarkable mechanism which allows the conjoined tendons of the interossei and lumbricales either to flex the proximal finger joint or to extend the distal two finger joints ac

FIG. 395 (*Top*) Insertion of the lumbricalis and interosseus into the aponeurosis. A pull on either flexes the proximal joint by the transverse fibers, which form a sling over the dorsum of the proximal phalanx.

(*Center*) The lumbricalis is pulled.

(*Bottom*) The interosseus is pulled. (Courtesy of Jour Bone and Joint Surg., 24 11 No 1 Jan 1942)

FIG 396 Stabilization of the proximal joint in extension by the long extensor tendon pulls the aponeurotic sleeve proximally until it is over the joint (A) The intrinsic muscles then pull on the lateral band and extend the distal two joints (D) A shift of the aponeurotic sleeve distalward changes their function to flexors of the proximal joint (B) and (C) In (A) and (B) a probe marks the joint, and a hemostat on the aponeurosis shows the shift. (Courtesy Jour Bone and Joint Surg., 24 11 1942)

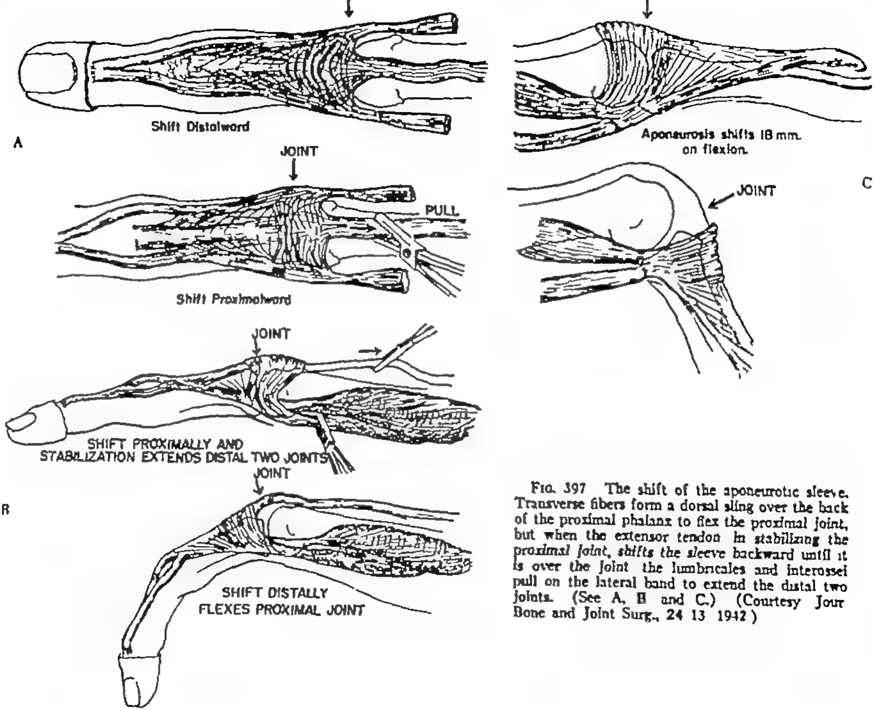


FIG. 397 The shift of the aponeurotic sleeve. Transverse fibers form a dorsal sling over the back of the proximal phalanx to flex the proximal joint, but when the extensor tendon in stabilizing the *proximal joint, shifts the sleeve* backward until it is over the joint the lumbricales and interossei pull on the lateral band to extend the distal two joints. (See A, B and C.) (Courtesy Jour Bone and Joint Surg., 24 13 1942)

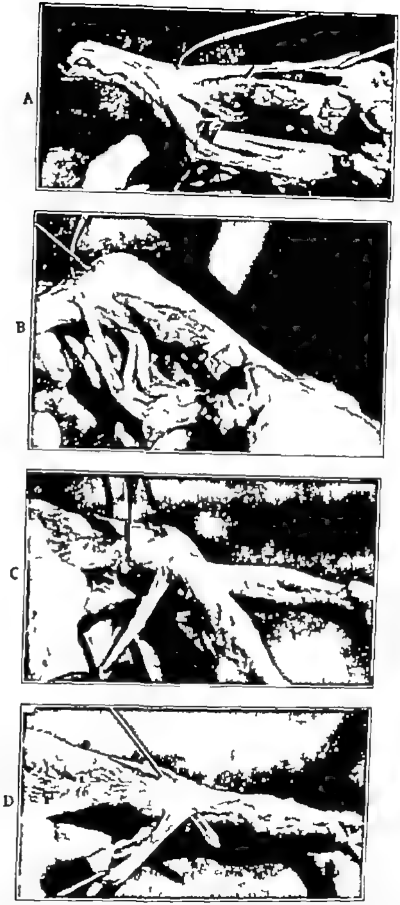


FIG 396 Stabilization of the proximal joint in extension by the long extensor tendon pulls the aponeurotic sleeve proximally until it is over the joint (A) The intrinsic muscles then pull on the lateral band and extend the distal two joints (D) A shift of the aponeurotic sleeve distalward changes their function to flexors of the proximal joint (B) and (C) In (A) and (B) a probe marks the joint, and a hemostat on the aponeurosis shows the shift. (Courtesy Jour Bone and Joint Surg 24 11 1942)

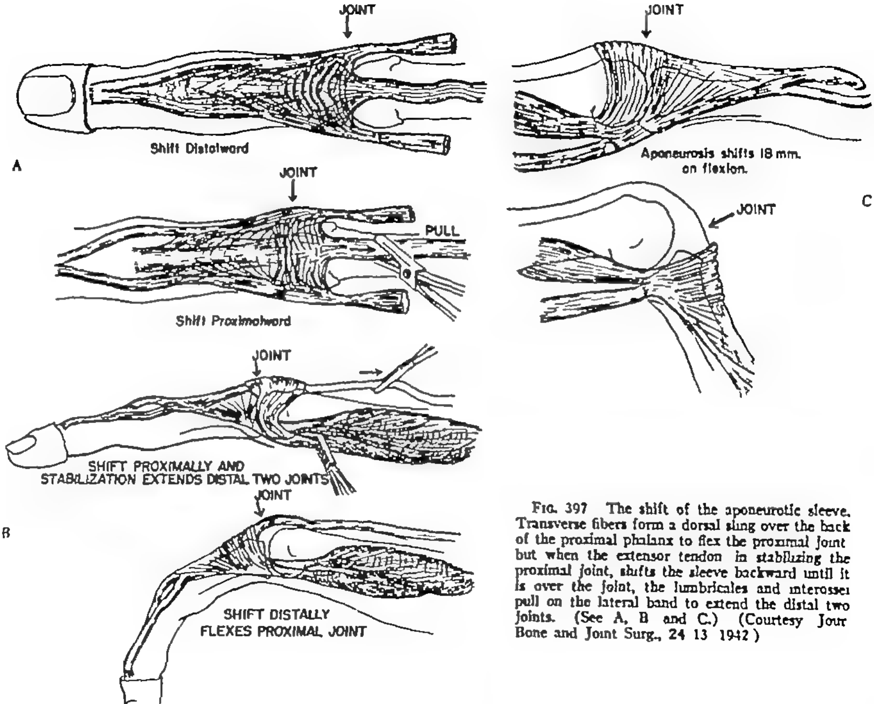


FIG. 397 The shift of the aponeurotic sleeve. Transverse fibers form a dorsal sling over the back of the proximal phalanx to flex the proximal joint but when the extensor tendon in stabilizing the proximal joint, shifts the sleeve backward until it is over the joint, the lumbricales and interossei pull on the lateral band to extend the distal two joints. (See A, B and C.) (Courtesy Jour Bone and Joint Surg., 24 13 1942)

cording to whether the aponeurotic sleeve shifts distalward or proximalward, respec tively The transverse fibers, constituting the broad strap of dorsal aponeurosis across the back of the proximal phalanx, the aponeurosis proximally, stabilizes the proximal joint in extension. The pull of the intrinsic muscles then is made automatically on the other branch of the Y of its tendon—the lateral band—and by it

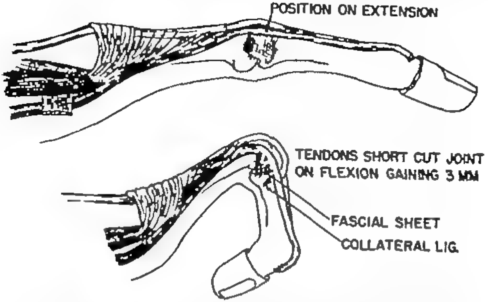


Fig. 398. The volar shift of the two lateral bands at the middle joint. On flexion the two lateral sheets automatically displace the tendons, so that they short-cut across the joint. (Courtesy Jour Bone and Joint Surg., 24 17 1942)

form the dorsal two-thirds of the sleeve. The ventral portion consists of a narrow band, blended with the joint capsule, and joining to the under surface of the aponeu rosis laterally The dorsal part of the sleeve, in company with the extensor ten don, can be passively made to shift on the phalanx longitudinally 15 mm., but the ventral portion only 3 mm The dorsal por tion, when in ordinary use, shifts on the phalanx about 7 mm, just enough for its thickened portion to lie across the phalanx or over the joint.

When the sleeve is distalward down the back of the phalanx, the intrinsic muscles can flex the proximal finger joints, but when the sleeve is drawn proximalward by the action of the long extensor tendon, the sleeve is over the proximal joint itself, thus robbing the intrinsic muscles of their lev erage on the phalanx for use in flexing It is like the shifting of gears At the same time the long extensor tendon in shifting extends the distal two finger joints or im parts lateral motion. The transverse fiber branch of the Y slackens from the shift of the sleeve proximally Therefore, when the long extensor stabilizes the proximal joint in extension, the intrinsic muscles extend the distal two joints. They flex the proxi mal joint only when the long extensor is relaxed.

Tendon Shift Volarward at Middle Finger Joint. The two lateral aponeurotic bands, which at the middle joint are in a rather dorsal position are, as this joint flexes, seen to shift volarward one-fourth of the thickness of the finger, so as to short cut this joint. This volar shift yields 3 mm. of slack in the extensor tendon of the distal joint, which is important in repairing the insertion. Each main lateral band forks to spiral and lateral tendon slips to extend the middle and distal joints respec tively, and has just 8 to 9 mm of motion to extend these two joints. On flexion of

these joints, however, the lateral forks must shortcut across the middle joint, so that the above limited excursion of the main lateral band will allow both the middle and distal joints to be flexed at the same time. The

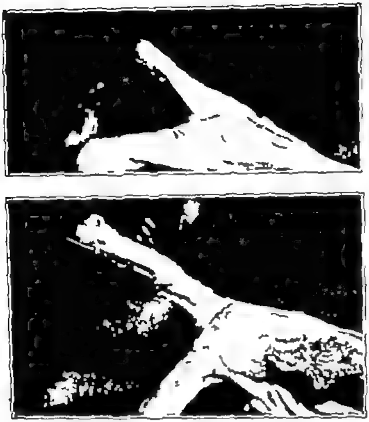


FIG. 399 (*Top*) Showing the volar shift of the lateral bands on flexing the middle joint.
(*Bottom*) Shows the resumption of the dorsal position of the bands on extension. A probe passes under the lateral sheet, which is attached to the collateral ligament and middle phalanx, and automatically causes the volar shift. (Courtesy Jour Bone and Joint Surg., 24 18 1942)

shift conserves the longitudinal amplitude of the tendon bands and allows both joints to function These lateral bands are kept from diverging from each other over the middle phalanx by the thin triangular ligament which spans between them. Each is forced to shift, on flexion, by a thin sheet of fascia extending from it to the fascia and insertion of the collateral ligament of the joint on the side of the base of the middle phalanx. On flexion, the pull of this sheet automatically displaces the tendon volarward with the phalanx.

Lumbricales These four small muscles, named from their resemblance to a worm, have both origin and insertion on tendons of other muscles Located on the radial sides of the digits, after arising by one or two heads from the profundus tendons, they lie between the tendons of the profundus and sublimis, are flat, and each is intimately wrapped half around the sublimis tendon. They then diverge radialward from the sublimis and pass in front of the slippery flat transverse metacarpal ligament, which spans the distance between the heads of the metacarpals and lies in front of the interosseus spaces, separating the lumbricales from the interossei The lumbricalis, in crossing the transverse metacarpal ligament, passes over the radial condyle of the

metacarpal, and from there turns dorsalward to join the tendon of the interosseus just distal and lateral to that muscle, to form the outermost fibers of the lateral band or expansion of the dorsal aponeurosis, and also the transverse fibers which loop over the back of the phalanx.

In the turn dorsally, as it passes over the radial condyle of the metacarpal, the lumbricalis makes an angle of approach to the phalanx of 35° for good flexion action

When the long extensor tendon is taut, the lumbricalis extends the distal two finger joints and gives some radial lateral motion but when the long extensor tendon is slack, *the lumbricalis flexes the proximal finger joint and nothing more.* Lumbricalis action in extending the distal two finger joints is strong when the proximal joint is held fully extended, but lessens as this joint flexes through its first 45°, or one-half of its range. Beyond this lumbricalis action soon becomes nil, as this function is taken up by the long extensors.

The lumbricalis initiates flexion of the *proximal finger joint*, even when the latter is in hyperextension, and carries through its complete range of flexion The long flexor tendons alone can also flex these *joints strongly*, as is seen in cases of median and ulnar palsy The lumbricalis is dependent also on its origin from the flexor profundus tendon, and this must first be tense *A profundus tendon*, also through the lumbricalis, flexes the proximal joint or aids in extending the distal two In extending the fingers, the lumbricales *aid, not only* in extending the distal two joints, but also in drawing the profundi distalward to allow the fingers to extend freely

A

B

FIG. 400 When the proximal joint is stabilised in extension by the long extensor tendon, the lumbricales and interossei impart lateral motion to the finger In both (A) and (B) the long extensor is taut in (A) the interosseus is relaxed and in (B) it is pulled upon, imparting lateral motion. (Courtesy Jour Bone and Joint Surg., 24 16 1942)

Interossei. *The four dorsal* interossei abduct the fingers from the long finger as an axis, and the three palmar interossei adduct them toward the axis. *The dorsal*

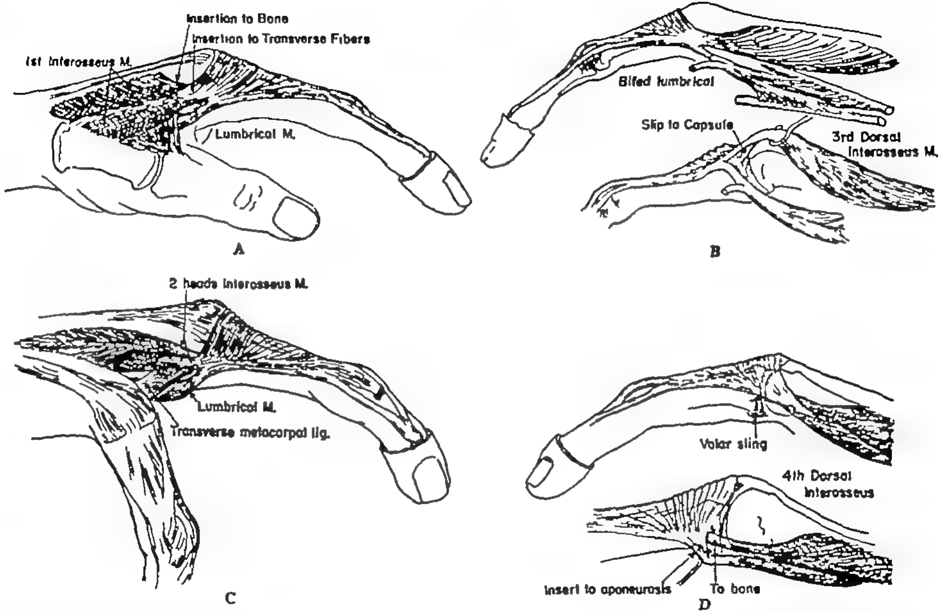


FIG 401 Showing types of *insertions.* Lumbricales insert into the dorsal aponeurosis Interossei by several heads from fairly distinct muscle bellies insert variously into the phalangeal tubercle (A), (B) (C) and (D), into the capsule of the joint (B) and into the aponeurosis (A) (B) and (C) (Courtesy Jour Bone and Joint Surg., 24 9 Jan., 1942)

ones insert by separate slips to bone, capsule, and tendon, but the palmar ones insert mostly to tendon with an occasional slip to capsule. In man, most of the interossei have three different types of insertion one on the lateral tubercle of the phalanx, which is somewhat ventral to the midline, another by a small slip to the side of the joint capsule, which in turn is transmitted both dorsally by some transverse fibers to the sling of the dorsal aponeurosis, and longitudinally through the capsule to the side of the phalanx and a third to the lateral band or expansion of the dorsal aponeurosis.

The first dorsal interosseus is unique in inserting into the lateral tubercle and into that part of the aponeurosis which transmits its pull to the *transverse fibers only*, but has practically no action of extension on the distal two joints The interossei in the third cleft, and occasionally in the second cleft, may be devoid of insertion on the tubercle, but they usually send a slip to the joint capsule as already explained

Between any two finger metacarpals, a typical arrangement of the dorsal interosseus is to have two bellies more or less fused, each of which takes its origin from each of the contiguous metacarpals. The superficial one runs volarward, crossing either radialward or ulnarward over the deep one to insert deeply either to the tubercle or capsule of the joint. The deeper belly inclines dorsally and inserts into the lateral band, sending a small slip to the capsule. This separates somewhat the functions of these two muscle bellies—the one to the bone flexing and giving lateral motion to the proximal joint, and the other in addition to this giving extension of the distal two joints.

An interosseus muscle belly blends to tendon opposite the proximal part of the metacarpal head. If the tendon goes to the tubercle it is usually rounded and almost 2 cm. long If it goes to the lateral band it is flat and in the sagittal plane and 1 cm. long. As it continues into the lateral band it rotates *about one-quarter circle*. The slip, if present, that inserts into the capsule usually comes off the deep surface of this tendon. It is about 2 mm. long and can be further separated with an instrument for about 5 mm from the ventral sling of the circular sleeve. An interosseus muscle may, though not usually, give a strong tendon to the lateral band even on the side where a lumbricalis is present.

The first dorsal interosseus muscle arises from two distinct bellies, the larger and deeper one having its origin on the thumb metacarpal and reaching the dorsal aponeurosis over the smaller superficial belly of the index metacarpal with a roll like that of the pectoral muscle The belly from the *index metacarpal dives under it and inserts* on the lateral tubercle This belly has better action in finishing the motion of flexion, but the thumb belly helps in pinching with the thumb against the index finger Both bellies flex the proximal finger joint when the long extensor is slack and strongly abduct the index finger when the long extensor stabilizes the proximal joint in extension. This interosseus muscle practically does not extend the distal two finger joints at all. The lumbricalis on that side and the palmar interosseus on the other attend to that.

The function of all the interossei is to flex the proximal finger joints when the long extensor tendon is slack. When the long extensor tendon stabilizes the proximal joint in extension by retracting the aponeurotic sleeve as previously described, the interossei furnish lateral motion to the fingers and, with the exception of the first dorsal one, also extend the distal two finger joints. The interossei thus have the same functions as the lumbricales, but they are stronger in all the motions. The lumbricales give weak lateral movement, but have *the advantage of angle of approach* in starting flexion. They also have a longer range of movement, counting the additional help of the flexor profundus.

The interossei give *lateral motion by any* of their insertions band, capsule, or tubercle, but that from the latter is slightly stronger The interossei initiate flexion of the proximal finger joints all the way from the straight position to that of full flexion and, along with the lumbricales, add considerable strength to the grip In ulnar paralysis the grip is about two-thirds normal.

Extension of the distal two finger joints by the interossei and lumbricales is strong when the proximal finger joints are straight or hyperextended but, as they flex to near 45°, the action of the interossei and lumbricales becomes less, and beyond 45° it becomes negligible. During flexion of the proximal joint, the long extensor takes on more and more the duty of extending the distal two joints and its maximum action is reached when the proximal joint is three-fourths flexed, from that point it recedes, especially in the distal joint.

The nerve supply enters basally between the palmar and dorsal interossei and is normally from the ulna, though, as found by Cunningham and others, the first, second, or even the third interosseus muscle may have some supply from the median nerve as in lower mammals The variations in interossei that occur are largely those seen in other primates.

Long Extensor Tendon of Finger The long extensor tendon is synergic in action with the intrinsic muscles. Alone it extends the proximal finger joints to hyperextension. Extension of the distal two finger joints is by the intrinsic muscles or the long extensor, depending on whether the proximal finger joint is flexed less or more than 45°, as has been stated

The gradation between the action of the intrinsic muscles and long extensor is gradual, with the balance of power changing when the proximal joints are at about 45° of flexion There is, therefore power of extension of the distal two joints by either the intrinsics or long extensor throughout *the range, with one exception* When the proximal and midlde joints are fully flexed they so tighten the long extensor tendon that it no longer can act on the distal joint, which is then powerless to extend

The long extensor tendon sends a slip of insertion from its under surface to the base of the proximal phalanx and a central slip to insert on the base of the middle phalanx. These slips, especially the former, limit the excursion of the main tendon With the finger free, the excursion of the tendon averages 14 mm for the motion of the proximal joint, but when the proximal joint is straight only 5 mm for the middle joint and 1 mm for the distal joint. The maximal force of extension of the distal two joints by the long extensor is when the proximal joint is flexed three fourths. With flexion beyond this the proximal slip of insertion holds so that the distal two joints lose much of their power of extension When the proximal and middle joints are flexed we cannot straighten the distal joint. When even the middle joint alone is fully flexed passively, which shifts the lateral bands volarward, the distal joint is helpless to extend.

In the chimpanzee a strong pull on the extensor tendon hyperextends the proximal joint and then the distal joints are only slightly flexed When the proximal joint is held from overextending the middle joint fully extends and the distal almost so As an atavism of this sort I recently saw a patient with complete severance of the ulnar nerve which I verified at operation Still, he could hyperextend all the joints of his ring and little fingers.

The long extensor tendon has the second important function of stabilizing the proximal finger joint in extension, so that only then can the intrinsic muscles extend the distal two finger joints and impart lateral motion to the finger

Hypothenar Muscles The abductor minimi digiti inserts on the lateral tubercle of the proximal phalanx and the joint cap-

sule, and sends out transverse fibers and a lateral band like that of the interossei. It does not, however, extend the distal two joints. It flexes the proximal joint when the long extensor tendon is slack, and abducts it from the hand when the long extensor stabilizes the proximal joint in extension The opponens minimi digiti opposes the little finger to some extent, similar to the opposition in the thumb. The thenar and hypothenar muscles, with the exception of the two abductors, maintain the carpal arches.

Movements of Hand in General Lateral movement of the fingers is possible only when the proximal joints are straight or nearly so Absence of side motion when in flexion is desirable as it gives firmness

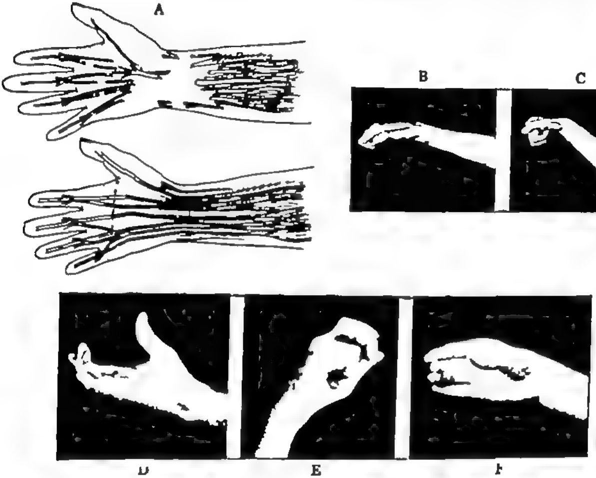


FIG. 402 Case R. M. All the flexor tendons and the three main nerves were crushed off above the wrist. Amplitude of motion in fingers was only one inch.

(A) After healing the condition found at operation is shown in the upper drawing and what was done in the lower Flexor tendons were joined by eight tendon grafts from palmaris and extensors of toes. Six nerve sutures were done to the median and ulnar nerves including two branches each of the radial and posterior branch of the ulnar

(B and C) Three years later sensation had returned but function of the intrinsic muscles was insufficient to prevent the deformity of the thumb at the side clawhand. The adherent tendons accentuated the claw Photographs show deformity and limitation of flexion, extension, and opposition.

A secondary operation was done to restore muscle balance. The flexor tendons were freed to finger ends, elongated and paratenon from the thigh was grafted beneath them. The sublimis tendons were removed from fingers, inserting them into the interosseus tendons in the distal part of the palm. A pulley operation was done for opposition of the thumb using the flexor ulnaris muscle, a grafted pulley and the tendon of the extensor pollicis brevis.

(D and E) Showing restored muscle balance extension and flexion.

(F) Showing opposition of thumb.

to the grasp When the joint is straight the proximal phalanx has free lateral motion on the narrow vertical saddle-like end of the metacarpal, and the collateral ligaments are loose In flexion the phalanx slides volarward on an ever widening articular surface. The collateral ligaments tighten, and, in full flexion, the flat end of the phalanx rests on the broad flat volar aspect of the head of the metacarpal, preventing all lateral movement

One should not mistake the spread of the fingers, when in full extension by the long extensors, for action of intrinsic muscles, because this is due in part to the curve of the metacarpal arch and to some extent also to muscle tension, aligning the phalanges with the metacarpals which diverge a little. Lateral movement by intrinsic muscles is possible only when the proximal joints are stabilized in extension by the long extensors It should be tested by the individual lateral motion of the fingers when the proximal joints are in slight flexion. Strength and width of spread show it only when compared with that in the other hand.

The action of tendons and muscles in the hand can readily be checked by feeling one's own hand when the fingers are working against resistance. Thus one feels lateral bands, aponeurotic and volar shifts, long extensor tendons, lumbricales, and profundus tendons in the various movements.

In normal muscle balance between the long extensors, long flexors, and intrinsic muscles, the hand assumes a position with the wrist slightly dorsi and ulnar flexed, the fingers partially flexed in all joints, with increasing degree of flexion from the index to the little finger The thumb is forward from the hand, partly flexed and in mild opposition and the normal arches are present. In this position of function, the mechanics of the hand are at their best.

Every motion of the hand is done with balance of muscle pull or coordination between several muscles in synergic action It has been seen how the work of extending a finger from full flexion falls first on the long extensor, but, as the extension progresses, is gradually taken over by the intrinsic muscles, the long extensor having changed to an extensor and stabilizer of the proximal joint. Practically, it can be considered that the intrinsic muscles extend the distal two joints in the first half, or 45°, of flexion of the proximal joint, and that the long extensor tendon extends them when the proximal joint is in the last half of the range of flexion, though, of course, transmission of function is gradual

The separate functions of the intrinsic muscles are dependent on the stabilization of the proximal finger joints in extension by the long extensors Without this they flex the proximal joints, with it they extend the distal two joints, and by pulling alternately they can give lateral motion.

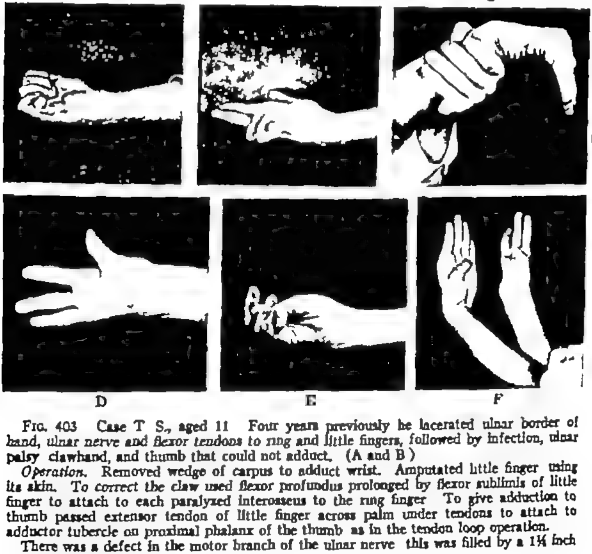
The mechanism of volar shift of the two lateral extensor bands at the middle joint is effective in conserving the limited amplitude of the various muscles The whole arrangement in the finger shows perfect synchronism, each muscle and tendon doing its part, conserving its limited amplitude of motion and so relaying its action that by coordination with each other the complete motion is carried out.

Clinical Types of Loss of Intrinsic Muscles of Hand

The long flexors can completely flex each of the three finger joints, but without the intrinsic hand muscles the finger tips in full flexion usually touch only the bases of the fingers, and are not flexed into the palm, the proximal joint remaining straight. There seems to be not enough amplitude of motion of the long flexor tendons to flex the proximal joints at the same time, help from the lumbricales and interossei is needed. This becomes more prominent as the claw deformity becomes fixed Also,

when the proximal joints are partially flexed by the long flexors, the distal two joints cannot be extended at the same time, *as again the intrinsic* muscles are needed The following is a test for presence of lumbrical in absence *of interosseus muscles* The distal two joints can be extended but when so doing the flexor profundus tendons are tense and a lateral band may be felt on only the radial side of the finger Integrity of carpal and metacarpal arches and opposition of the thumb and little finger are wholly dependent on the thenar and hypothenar muscles with the negligible help of the palmaris longus. If the adductors of the thumb are not functioning, the thumb loses part of its range of motion across the hand and its force in adducting toward the hand. When *lateral motion of a digit* is lost such as abduction of the index finger, the finger inclines ulnarward which upsets the mechanics for good finger function When the index

A B C



D E F

FIG. 403 Case T S., aged 11 Four years previously he lacerated ulnar border of hand, *ulnar nerve and flexor tendons to ring* and little fingers, followed by infection, ulnar palsy clawhand, and thumb that could not adduct. (A and B)

Operation. Removed wedge of carpus to adduct wrist. Amputated little finger using its skin. To correct the claw used flexor profundus prolonged by flexor sublimis of little finger to attach to each paralyzed interosseus to the ring finger To give adduction to thumb passed extensor tendon of little finger across palm under tendons to attach to adductor tubercle on proximal phalanx of the thumb as in the tendon loop operation.

There was a defect in the motor branch of the ulnar nerve this was filled by a 1¼ inch graft from one of the sensory branches.

Two years later the tendons were freed and some paratenon *from fascia lata* was grafted beneath them.

Examination two years later showed excellent function of the hand.

(C) The ring finger could flex in its proximal joint and at the same time extend in its distal two joints.

(D E, and F) The thumb could adduct as well as could the other thumb, and the arches of the hand were well curved. The transferred tendon for adduction could be felt moving about the ulnar border of the hand and due to the nerve *graft the adductor* muscles of the thumb could be felt to move.

finger cannot abduct against the thumb and the thumb cannot adduct against the index finger, the pinch between these two is poor

When such imbalance remains, the unopposed strong muscles increase the deformity until it is structural—as is seen in long standing cases of ulnar, or ulnar plus median, paralysis—necessitating correction of position before restoring muscle balance.

In ulnar paralysis, when repair of the nerve is no longer possible, there is need for restoration of carpal and metacarpal arches and for restoration of the ability to adduct the thumb and abduct the index finger Also the muscle balance may be restored to the little and ring fingers

In combined ulnar and median paralysis, when it is not reparable by nerve suture, there is greater need for restoring carpal and metacarpal arches, all fingers are

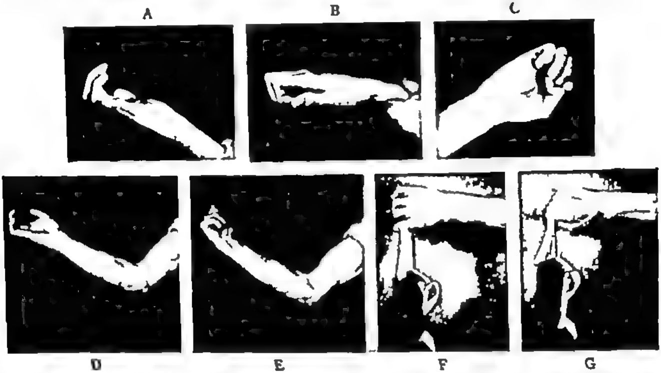


FIG. 404 Case J A. C. Restoration of muscle balance to intrinsic muscles in hand. Right arm was pulled between belt and pulley fracturing the humerus and crushing off the median ulnar and internal cutaneous nerves high in the arm. These were sutured There was between the end of the musculocutaneous a three inch gap, of the ulnar one of four inches and of the median one of five inches. These were overcome by flexing neck, shoulder and elbow and transplanting the ulnar nerve at the elbow

In a year the flexors in the forearm worked well, but not the intrinsic muscles, and sensation returned throughout except beyond the middle finger joints.

By one and one half years sensation had returned completely throughout though not yet to normal degree in fingertips. The intrinsic muscles did not recover except slightly in the two eminences, but as the flexors in the forearm became strong and he had not worn his splint there had become established strong clawhand with thumb at the side.

(A, B and C) Showing clawing flathand, limits of extension and flexion of fingers and of opposition of thumb. Because of his useless hand he was not able to find occupation.

Operation was done for muscle balance in the fingers. Also, for opposition of the thumb he had a pulley operation and for adduction of the thumb and curvature of the arches a tendon T operation.

(D and E) Taken two years later showing fairly good muscle balance in the fingers and a practical opening and closing for grasp. The thumb now adducts to the ulnar side of the ring finger and opposes to two inches in front of the long finger and he has curvature of both carpal and metacarpal arches. Good sensation throughout and stereognosis returned. He works well as a welder

(F and G) Showing strong lateral motion of the index finger lifting a heavy Scotch tape weight. In the operation for muscle balance the sublimis of this finger was transferred to the lateral band of the dorsal aponeurosis to act as an interosseus muscle.

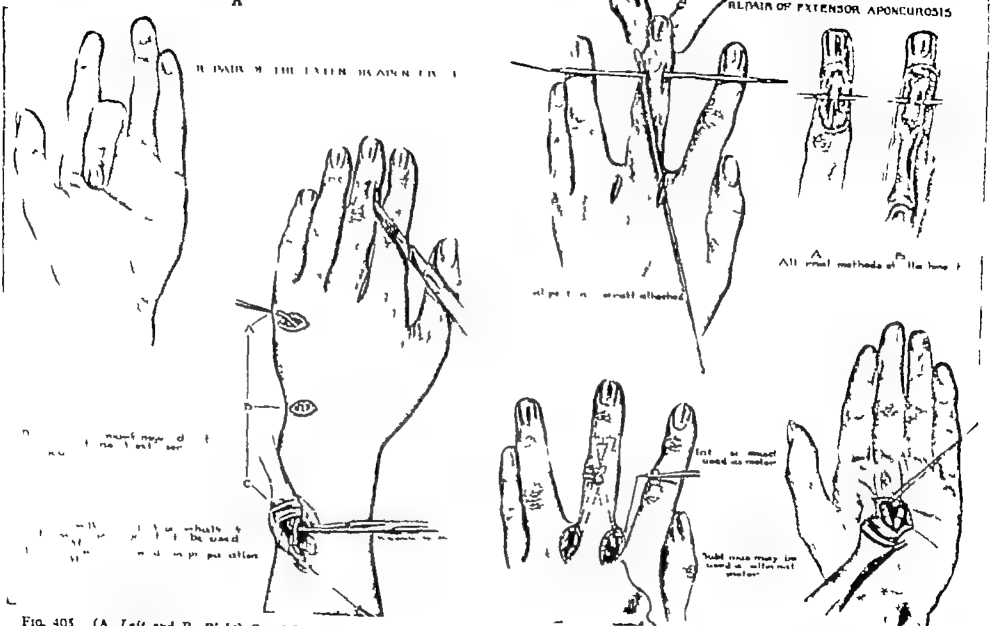


FIG. 405 (A, *Left* and B *Right*) Supplying new extensor tendon for the middle finger joint, using a slender tendon as a graft and crossing it over the middle finger joint. It is motored by the interossei muscles or if they are paralyzed or more strength is desired, by the *sublimis tendon.* (S B Fowler Major M.C., Baker General Hospital.)

A

B

C

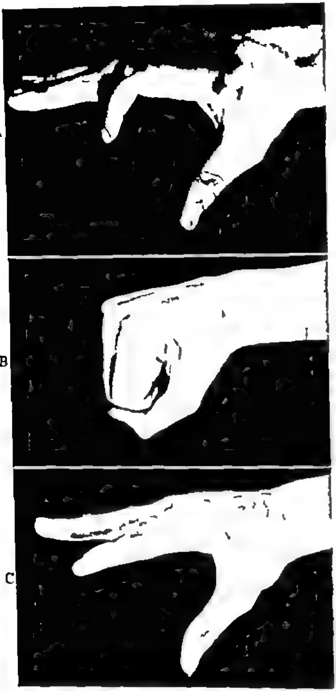


FIG. 406 (A, *Top*) Preoperative. Due to a gunshot wound the second metacarpal was fractured and the proximal finger joint stiffened Also the patient could not extend the middle finger joint, as the interosseus muscles were injured

(B *Center* and C *Bottom*) Postoperative Motion was given the proximal finger joint by capsulectomy, and the middle finger joint by the crosstendon graft method of Fowler activating the graft by fastening it to the sublimis tendon in the palm. (Courtesy of S B Fowler Major M C., Baker General Hospital.)

A

FIG. 407 (A *Top*) Limit of extension of middle joint because its extensor tendon was severed by a shell fragment.

(B *Bottom*) Result after repair by method of Fowler using as graft an extensor tendon from the little finger passing it transversely through a drill hole in the middle phalanx, crossing the ends over the dorsum of the middle joint and fastening them to the interosseus tendon on each side (Courtesy of S B Fowler Major M C., Baker General Hospital.)

B

A

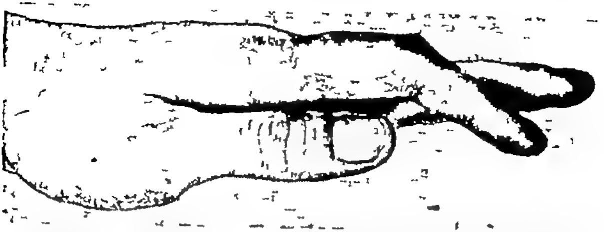


FIG 408 (A *Top*) Due to an open fracture of the proximal phalanx, the extensor tendon was ruptured. The position of phalanx was first corrected by osteotomy. The patient cannot extend the middle finger joint. (B *Bottom*) Excellent movement of middle finger joint was by the cross-tendon graft method of Fowler using extensor tendon of little finger and fastening it into the interossei. (Courtesy of S B Fowler Major M C., Baker General Hospital.)

B

clawed and need return of muscle balance. The thumb is useless at the side of the hand and needs opposition and adduction. In poliomyelitis, the intrinsic muscles are often selectively paralyzed.

In the clawhand of Volkmann's ischemic paralysis, the imbalance is from contracture overpull of the long flexors and also from a degree of paralysis of the intrinsic muscles. The latter is due to the ulnar nerve's being affected by the ischemia when in the fascial enclosure of the forearm, and by the subsequent strangling by cicatrix.

Hands that have been ravaged by infection show the same type of deformity that is seen in ulnar and median nerve paralysis (*fingers clawed, hand flat, and thumb at the side*), because during the infection the intrinsic muscles were paralyzed by being bathed in pus. Moreover, infection travels up the forearm along the course of the two nerves. Cicatricial strangling of muscles and nerves follows, and thus fixes the deformity of imbalance. Other cases for repair are those caused by direct injuries which destroy some of the intrinsic muscles of the hand or leave them immobile in cicatrix.

Rupture of the middle extensor slip near its insertion to the base of the middle phalanx results in the deformity of hyperextension of the proximal joint, flexion of the middle joint, and hyperextension of the distal joint. This "boutonnière" deformity has been ascribed to a central longitudinal tear in the extensor tendon, which allows the two lateral slips to separate and move volarward, so that the joint herniates

through the slit. The lateral slips then act as flexors for the middle joint, thus increasing the deformity This, however, is the result of first severing the middle slip Then as the joint is flexed, the buttonhole tear occurs secondarily

Two other deformities are common in fingers. One is drop finger at the distal joint, due to bone evulsion or rupture of the extensor tendon insertion This may be considered the insertion of the intrinsic muscles when the proximal joint is in extension, and of the long extensor tendon when it is well flexed

The other is hyperextension of the middle joint with flexion of the distal joint from rupture of the anterior part of the capsule of the middle joint. It also exists normally in some people, and in these the long extensor is seen to stand out as a strong double cord running to the middle joint and over extending it The flexor profundus then automatically draws the distal joint into flexion This occurs in double jointed people with laxness of the anterior part of the capsule of the middle joint.

Much paralysis of intrinsic muscles and deformity is found in lepers due to degeneration of the nerves Surgery for this is being carried out in the leper colony at

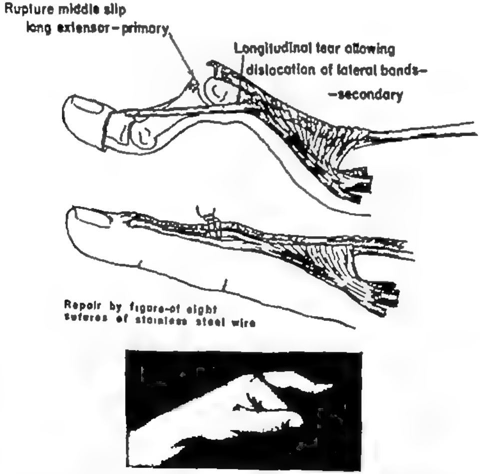


FIG. 409 (*Top*) The "*boutonnière*" deformity is caused by rupture of the central extensor tendon slip at the middle joint and a subsequent tear of the aponeurosis. The lateral bands then flex the middle joint and extend the distal joint.

A simple figure-of-eight removable stitch of stainless-steel wire, together with splinting is sufficient to cure a recent case. In a long standing case the slit also should be closed by a removable figure-of-eight suture through the skin and tendon. (Courtesy Jour Bone and Joint Surg., 24.20 1942)

(*Bottom*) The deformity

Carville, La, by Dr Riordan. Fortunately, leprosy now can be arrested.

Treatment

Nerve suture for ulnar or median paralysis should be done if it is mechanically possible, and if the interval since the paralysis has not been so long that fibrous degeneration of muscle has been established to the point where even the reaction of degeneration is no longer present. The tiny motor branches of the ulnar and median nerves in the palm are not too small to suture with good results, as shown in 36 personal cases. Operations for tendon transfer in such paralysis are only for patients in whom the nerve injury is irreparable, and the long flexor muscles of the fingers are intact. If the deformity is easily corrected passively, the nerve and muscles alone are to blame, but if firm structural changes have set in these must first be corrected by the usual methods of mild prolonged tension, capsulectomies osteotomies, etc. *Postinfection* cases are not suitable for tendon transfer in a finger unless the tissues are flexible or unless by excision of cicatrix they can be made so

Discussion. The very thin and complicated dorsal aponeurosis is too delicate for the usual surgical repair by suture, and too readily adheres to the bone beneath. Therefore, the author has been using the

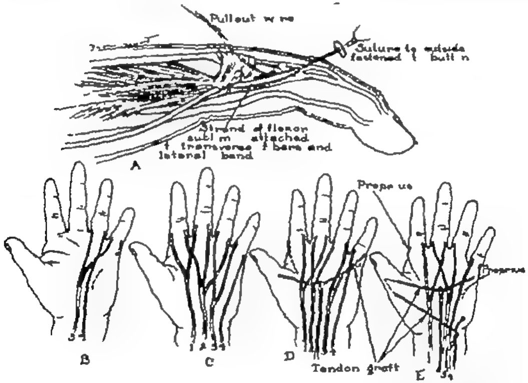


Fig. 410. In the operation to restore muscle balance in a finger after loss of the intrinsic muscles, the sublimis tendon, or a strip thereof follows a straight course through the *lumbricalis* canal and is inserted into the transverse fibers and lateral band of the dorsal aponeurosis, by a simple stitch of stainless-steel wire No 35 which passes on out through the skin to a button. The wire is removed by the pull-out wire in three weeks. The tendon and the dorsal surface of the lateral band have been scraped for better attachment. (B C, D and E) show combinations for placing tendons, so that the lateral motion supplied by each single tendon to several fingers will be in the same direction. Small numbers indicate which sublimis tendon is used.

In (D) is shown a combination with a tendon T operation for adduction of the thumb and restoration of the arches, and also an index long extensor used for abduction of the index finger In (E) is shown the same with the *addition of a* tendon for opposition of the thumb and another for abduction of the little finger

FIG. 411 Case C. M Q Repair of interosseus tendon by tendon graft.
Following striking a man in the teeth and immediate suture infection occurred resulting in ankylosis of the proximal joint of the index finger
Six months later an arthroplasty was done. At this time the tendon of the palmaris longus was used to fill a one and one-half inch gap in each of the long extensor tendon and the tendon of the first interosseus muscle, where they had sloughed from infection.
(*Left*) Flexion in proximal joint from arthroplasty
(*Center*) Abduction of the index finger (right) through the tendon graft in the interosseus tendon compared with that in other hand.
(*Right*) Adduction of the index finger compared with other hand.

thinnest and least irritating suture—stainless steel wire. The simplest stitch is used and placed so that it can be removed in three weeks by withdrawal

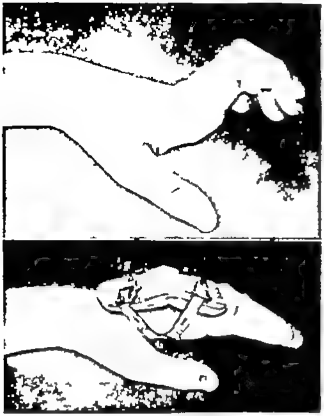
Sir Harold Stiles, in 1922, described an operation for claw finger He detached the flexor sublimis tendon from its insertion in the finger, split it, bringing each end around to the back of the finger and then suturing each to the extensor tendon with linen. He stated that he did not know the result as he was, due to the war, unable to follow the patients The author tried this operation twice, but each time it resulted in failure, as the finger had less movement than before. The delicate parts of the extensor tendon were not differentiated and all became bound firmly The suturing should not have been to the extensor tendon Also, the sublimis tendon had a tortuous course and penetrated through an annular band of fascia which favored adhesions. This operation does not consider the action on the transverse fibers and lateral band or the shift of the aponeurotic sleeve.

Operation to Restore Muscle Balance in Clawed Fingers The following is a new technic which is planned to give the least possible adhesions, a straight course for the tendon, good leverage and the normal angle of approach. The tendon juncture is made on the dorsal surface of the transverse fibers and the lateral band, where adhesions are not detrimental The gliding surface of the lateral band and dorsal aponeurosis is not disturbed. There is no permanent suture material left in the wound.

In this operation the flexor sublimis tendons are detached from their insertions, withdrawn from the palm, split, and then passed down the lumbrical canals to be attached to the transverse fibers and lateral bands in the finger The object is to restore muscle balance, to furnish extension to the distal two joints, to help flexion of the proximal joints, and to furnish lateral motion to the fingers The middle joint is already in flexion deformity, so the loss of the sublimis is of less importance.

Through a midlateral incision in the finger, the length of the proximal segment, the sublimis tendon is cut off through a nick in the sheath opposite the joint If cut too long, the stumps attach, making flexion contracture of the middle joint The tendon is withdrawn enough to slit it

A



B

Fig. 412 (A, *Left top*) Deformity from paralysis of intrinsic muscles resulting in clawed fingers. (B *Left bottom*) Splint used to flex proximal finger joints. The knucklebender splint is better

(C, D and E, *Right*) Muscle balance operation has been done in fingers sublimis tendons have from the palm been transferred down the lumbrical canals to insert into the lateral bands in the fingers. Note flexion of proximal joints and extension of distal two. Also ability to spread fingers. (Courtesy of William H Frackelton, Lt. Col., M.C., Beaumont General Hospital.)

C

D

E

an inch or more and then, through an L-shaped incision in the palm paralleling the creases, is withdrawn and split its length. If desired, it may be split in four with the back of a scalpel blade

A fine No 35 stainless steel wire with a needle on each end is sewed into the end of a strand of sublimis tendon, threading each needle back and forth twice through the tendon until the end of the tendon is reached, where the two ends of the wire will emerge A pull-out wire is placed through the loop of the wire for later removal The two end wires are threaded on one needle, which is passed down the lumbrical canal and on out the lateral incision in the finger and over the lateral band, the top surface of which is scraped to receive it The wires are then passed on across the finger and out through the dorsal skin, where they are fastened to a button The two ends of the pull-out wire are threaded on one needle and passed out through the skin proximally where they are left for use in pulling out the stitch three weeks later To remove the stitch the ends are cut off close to the skin and

the stitch is withdrawn backward by the pull-out wire A better method is to use the running suture shown in colored illustration

From the one lumbrical canal two tendon strands will pass one to each side of the aponeurosis, it will both flex the proximal finger joint and extend the distal two At tachment to the transverse fibers and lateral band will result if their contiguous surfaces are well scraped and they lie in

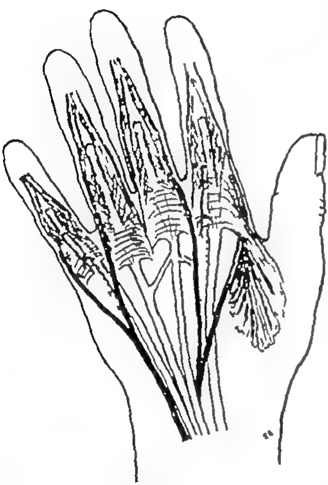


Fig. 413 For paralysis of interossei and lumbricali (paralytic clawhand) the two extensor proprius tendons may be each split and transferred to a lateral band of each finger to furnish spreading of the fingers and correction of muscle balance by extending the distal two finger joints. The proprius indicis and minimi digiti (shaded) are first dissected from their beds well down the fingers. The bordering aponeurosis is sutured as shown so the extensor tendons will not extend the joints in rotation The action is not so strong as when sublimi are used and to flex the proximal finger joints the proximal pulleys must be advanced in addition.

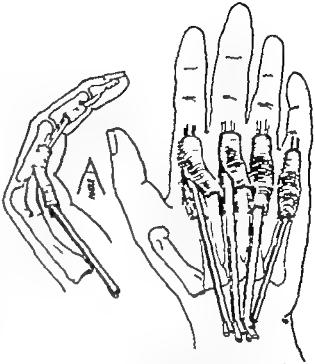


Fig. 414 Pulley advancement operation to increase voluntary flexion of proximal finger joints in clawhand. The proximal pulley is slit through on each side, avoiding the nerves, until there is a sufficient angle of approach for the long flexor tendons to act well on the proximal joints.

cleft. The bed of the tendon is in soft gliding tissue all the way The tendon should be threaded in and out the aponeurosis once as it passes the transverse fibers so that by taking advantage of the gliding close apposition while healing The tendon will be found to be the right length, reaching to within a centimeter of the middle joint on the dorsum of the finger

The split strands from any one tendon should go either all to the radial sides of the fingers or all to the ulnar sides, so that lateral motion will be possible, one tendon pulling two or more fingers radialward and another tendon ulnarward It should be planned that some tendons will abduct or spread from the middle finger and others will adduct or converge to the middle finger

One must plan to use to the best advantage whatever tendons are available If all sublimi, except that of the little finger which is tiny, are split in two, there are seven strands, some can be subdivided.

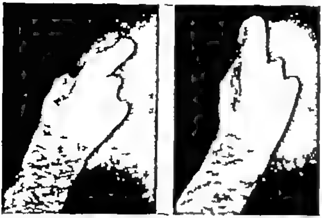


FIG. 415 Case H. F First interosseus and lumbricalis muscles are irreparable, producing the deformity of ulnar flexion in the proximal joint of the index finger
The extensor tendon of the amputated ring finger was transferred to that of the first interosseus muscle The illustrations show the strong lateral motion restored to the finger

Each finger should have at least one strand, so that the distal two joints will extend and the proximal joint will flex well. To the index and little fingers the tendon should be placed on the radial and ulnar sides, respectively, for abduction from the hand Their respective extensor proprius tendons can be used for this purpose if desired The sublimis tendon to the index finger should go to the lateral band instead of to the tubercle, if it is expected to extend the distal two joints It is advisable to transfer tendons to each side of each finger, but one must figure to have enough tendons for also furnishing adduction and perhaps opposition to the thumb Besides the sublimis tendons there are available the two extensor proprius tendons the palmaris longus, and even free tendon grafts from the palmaris longus or extensors of the small toes In a case of ulnar palsy in which the nerve is severed above the elbow, to use the sublimis, which is supplied by the median nerve, would rob the little finger of flexion, unless its profundus tendon could be joined to the profundus tendons in the forearm. The hand and fingers are splinted for three weeks with the wrist in flexion, followed by light motion for a week and refraining from hard work for two months.

This operation to restore muscle balance is useful on several or all fingers as in poliomyelitis or combined median and ulnar palsy, or may be used on one finger the intrinsic muscles of which have lost their function If flexion is given by capsulectomy or arthroplasty to a proximal finger joint and the intrinsic muscles to that finger are not working to maintain it, power of flexion may be given by transferring the sublimis tendon from the palm to the lateral band in the finger or by advancing the proximal pulleys

OTHER OPERATIONS TO RESTORE MUSCLE BALANCE FOR CLAWED FINGERS

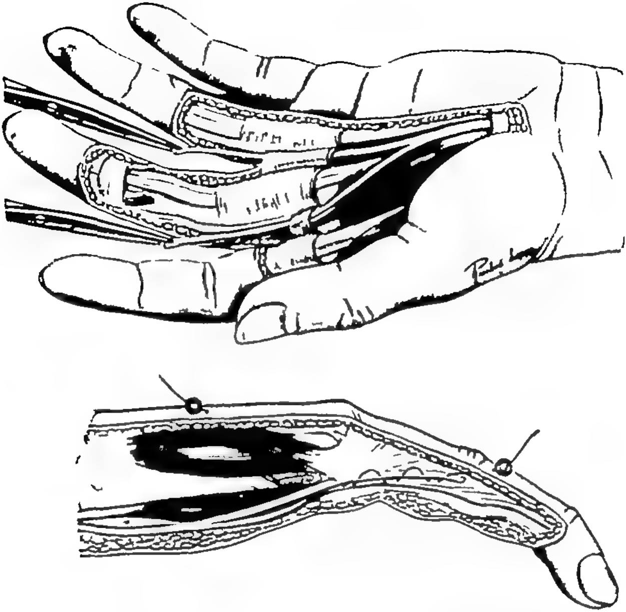
Sublimis transfer just described is the basic operation for restoring muscle balance in a finger, but of several other procedures each has its place depending on the amount of rigidity of deformity and the tendons that are available for transfer We need for combined median and ulnar palsy to gain opposition and adduction of the thumb curvature of the metacarpal arch, flexion of the proximal finger joints and at the same time extension of the distal two Lateral motion of the fingers is also valuable, especially of the two marginal ones.

Arthrodeses of Finger Joints. Arthrodeses give position of function and in some situations make possible better tendon action.

Middle Finger Joints. Extreme claw hand may be remedied by fusing the over flexed middle finger joints in a position of mild flexion. This will relieve the cocking back of the fingers and the flexor tendons will have more flexor action on the proximal finger joints This operation may be supplemented by advancing the proximal pulleys as described below so the long flexors will flex the proximal finger joints.

Proximal Finger Joints. In cases of severe hyperextension of these joints, arthrodesis of them is one solution. This relaxes the flexor tendons to allow the distal two joints to extend. Voluntary extension

PLATE 4



Operation to restore muscle balance in fingers in clawhand from paralysis of interosseus and lumbricalis muscles. The tendon of each flexor digitorum sublimis is split, transferred through a lumbrical canal and fastened to a lateral band of a dorsal aponeurosis by a removable stainless steel wire either by the pullout stitch or the running suture method

must then be given to the distal two joints by severing the insertions of the extensor tendons to the proximal phalanges and transferring some tendons (sublimis or proprius) to the lateral band of the dorsal aponeurosis

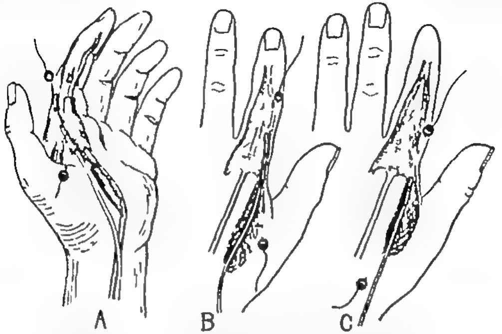


FIG. 416 Tendon transfers to give abduction to the index finger
(A) Flexor sublimis tendon detached at its insertion is withdrawn in the palm passed down the lumbrical canal and attached to the lateral band by a running stitch of withdrawable stainless steel This flexes the proximal finger joint, extends the distal two and abducts the finger
(B) In special cases in order to give more of an extension component, the sublimis tendon is withdrawn at the wrist passing it over the dorsum of the thenar eminence to gain the lateral band (Graham)
(C) The extensor pollicis brevis is transferred to act as the first interosseus band (Bruner) It reaches only to the tendon.

Proximal Finger Joint Affects Clawing Hyperextension of a proximal finger joint greatly increases clawing as this is a key joint in the muscle balance in a finger Flexing it lessens the clawing When a proximal finger joint in a clawhand is given flexion by capsulectomy the clawing will lessen due to the relaxation of the flexors Howard suggested gaining this position of flexion by sliding distalward a slab from the back of the knuckle as a bone block To correct clawing we should furnish flexion to this joint by some of the various methods

Correcting the position of one joint in a claw finger by bone block, fusion, arthrodesis, tenodesis of middle slip to proximal phalanx, or tendon transfer gives better muscle balance and action to the other finger joints

Transfer of the Proprius Tendons To extend the distal two finger joints and also spread the fingers, the extensor indicis proprius is slit down to its end, severed and split in two One end is looped about the interosseus tendon and sewed into the lateral band on the radial side of the index finger and the other to that of the long The proprius of the little finger is similarly slit down and divided into two One end is cut off and sewed into the lateral band on the ulnar side of the ring finger The other is left attached, but looped about the insertion of the abductor minimi digiti For this, the latter's insertion is cut and re sutured. This operation is supplemented by pulley slitting as described below

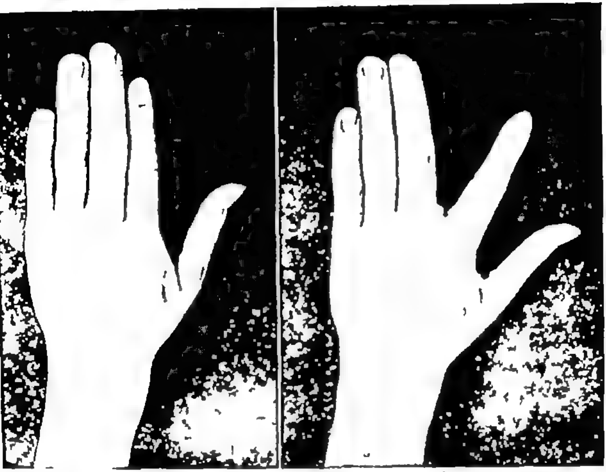
When transferring an extensor proprius tendon to a lateral band, a component of flexion of the proximal finger joint may be given by passing the tendon volar to the transverse metacarpal ligament. It will

FIG. 417 (*Left*) The index finger fell into adduction from ulnar palsy and could not be abducted. (*Right*) Sublimis tendon of finger was detached, drawn out at wrist and passed over back of thumb to attach to the lateral band on the radial side of the proximal segment of the index finger (Graham) Showing tendon beneath the skin and voluntary abduction gained. (Courtesy of Walter C. Graham, Lt. Col., M C., Valley Forge General Hospital.)

then have the same angle of approach to the proximal phalanx as a lumbrical namely 35 degrees (Fig 419) These transfers on the radial and ulnar sides of the hand flex *the proximal finger joints only if first looped* about the insertions of the first interosseus and the hypothenar muscles respectively on their way to the sides of the proximal phalanges This transfer for clawhand has weaker action than has sublimis transfer or the advancement of the proximal pulleys Some of its beneficial effect is by tenodesis due to the adhesions that form about the tendon holding the proximal finger joint in flexion

Severing of Extensor Insertion to Proximal Phalanx. In the chimpanzee when the long extensor tendon is pulled, all three finger joints extend but in man this action is snubbed in a percentage of cases by the attachment of the extensor tendon to the base of the proximal phalanx. Through *a small longitudinal incision in the tendon* this insertion to the phalanx may be severed. The long extensor will then extend all finger joints. *The slit in the aponeurosis is resutured.* Some fingers without this slip of insertion have voluntary extension of the distal two joints Error of interpreting that as intrinsic action is avoided by palpating the long extensor muscle. Suturing the lateral bands together at the middle joint will, if necessary, increase the action on the distal joint. Pulleys are cut as described below

Advancing Proximal Pulleys to Flex the Proximal Finger Joints (Fig 414) Normally the long flexor tendons flex the proximal finger joints only weakly as they parallel the finger instead of having a proper angle of approach to the proximal phalanx for strong flexion. Therefore, in



A B

FIG. 418 First interosseus muscle is paralyzed. Ability to abduct is given index finger by transferring tendon of extensor proprius indicis to tubercle on outer side of base of proximal phalanx. (A and B) Motion gained. Note pedicle graft over bullet wound that severed the motor nerve. (Courtesy of L. D Howard Lt. Col. M.C Wakeman General Hospital.)

paralysis of the intrinsic muscles, the pulley opposite the metacarpal head and base of the proximal phalanx may be advanced volarward, but still retain its gliding surface, by being slit through each side of it The volar digital nerves should be spared. The pulley is slit for from three-quarters of an inch to an inch or until a pull on the flexor tendon flexes the joint well. It is slit to almost the center of the proximal phalanx, leaving a little of the pulley intact to prevent excessive bowstringing of the tendon This operation supplements the four above operations for clawhand

Either this operation or the transfer of the sublimis tendon to the lateral band should be done in all cases of capsulectomy or arthroplasty of the proximal finger joints when the intrinsic muscles are not active to maintain the flexion so gained.

When clawhand becomes fixed the knucklebender splint will correct the position of fingers and thumb, but if the proximal finger joints are too rigid, capsulectomies will be necessary

Contracture of Intrinsic Muscles At the end of Chapter 5 is described Ischemic Contracture, Local in the Hand, in which the intrinsic muscles become contracted drawing the hand into the intrinsic plus position compared to its opposite position, which is that of intrinsic minus, or claw hand A mild degree of contracture of the intrinsic muscles which may be present in severe injuries helps to correct the muscle imbalance of clawhand Theoretically, we might, by placing fascial strips from the lateral bands up through the paralyzed interosseus muscles to the metacarpals, produce a tenodesis effect to give mild fixed flexion to the proximal finger joints and extension to the distal two If such fascial

strips could be activated by a long tendon in palm or wrist, there might be some of the action of a sublimis transfer

Operation to Furnish Abduction in Index Finger Frequently from local injury or ulnar palsy there is loss of the first dorsal interosseus muscle with adduction deformity of the index finger which greatly interferes with its function. (Fig 420) Strength of pinch between thumb and index finger depends not only on the long flexors but also on those two muscles that give side motion to the pinch, adductors of the thumb and the abductor of the index finger Transference of a tendon to act as the first interosseus muscle greatly helps a patient with ulnar palsy The extensor indicis proprius is slit free well down past the proximal finger joint and transferred around the first interosseus tendon and into the tubercle on the radial side of the proximal phalanx. Unless looped about the interosseus tendon it extends instead of abducts If the extensor communis tendon, instead of the proprius, were used, it would be necessary to suture its stub into the proprius tendon

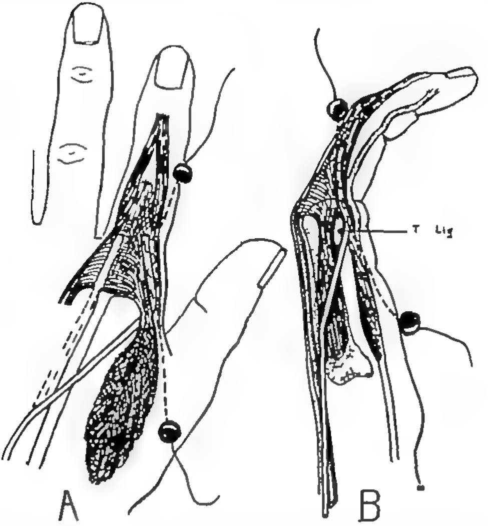


FIG. 419 Transfer of an extensor proprius tendon to act as an intrinsic muscle of the hand.

(A) In ulnar paralysis abduction for proper pinch is furnished the index finger by transferring the extensor indicis proprius to the lateral band of the dorsal aponeurosis. It is looped about the tendon of the first interosseus muscle *and fastened to the lateral band (after scraping each) by a* removable running suture of SS wire.

(B) When a flexion component is needed, an extensor proprius of the index or little finger may be transferred to the lateral band after passing it volar to the transverse metacarpal ligament.

so that the latter would pull symmetrically on the tendinous cap over the proximal joint of the index finger Loss of proprius shows on critical examination as only a slight rotation of the index finger and slightly less force in extending the proximal finger joint. Another tendon used to abduct the index finger is the short extensor of the thumb (Bruner), its insertion detached as far distally as possible In ulnar paralysis, in contrast to severed first interosseus tendons, only a little adduction of the index finger occurs, as there is no functioning muscle to exaggerate the deformity, but the operation is a real help in function as it gives power to abduct Similarly, the flexor sublimis tendon of the index or ring finger has been detached from its insertion, brought out above the wrist and passed subcutaneously back of the thumb through the dorsum of the hand to be attached to the lateral band in the finger (Graham) This has also some flexor action of the proximal finger joint. (Fig 416) If capsulectomy is done on the index or little finger, unless the outside collateral ligament is preserved it is especially necessary to provide a tendon to abduct each of these fingers from the hand to prevent the joints from being unstable.

In restoring abduction to the index finger, the action of the lumbrical tendon must be left free to preserve extension of the distal two joints

In case of loss of the index finger and its metacarpal, the long finger may go into adduction and need this operation. Similarly, abduction can be supplied to the little finger after loss of its abductor by using the extensor digiti quinti proprius. Any finger that stands alone may need strong lateral control furnished by a proprius, a sublimis or other extensor tendon.

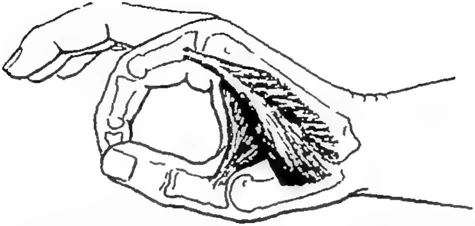
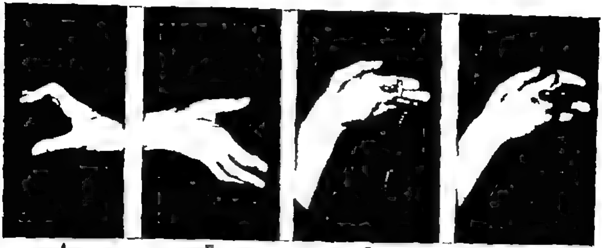


FIG. 420 Illustrating reason for the weak pinch in ulnar palsy the inability to make an O with the thumb and index finger and to scrape the extended thumb across the palm The abductor (first interosseus) of the index finger and the adductor of the thumb are necessary antagonists to give a firm pinch.

If an interosseus tendon is merely adherent to the bone from injury, a piece of deep fascia, if placed between tendon and bone with its gliding side outward, will allow movement. Cicatrix, if present over the site, should be replaced with a good flap of skin

Repair of Drop Finger If splint treatment is commenced within a week and maintained for five weeks, operation can usually be avoided The middle finger joint should be in flexion and the distal joint in extension, as this is the effective position for relaxing the tendon. Flexion of the middle joint gains 3 mm. of slack in the tendon Operation does not always result in motion. From the reaction of a silk suture, the tendon often adheres to the dorsum of the head of the middle phalanx.



A B C D

FIG. 421 Case C. S Restoration of action of intrinsic muscle.

Two years previously the hand was crushed in a press and the palm lacerated, resulting in loss of index finger intrinsic muscle of long finger and flexion contracture of that finger There was complaint of inability to work because the long finger was drawn into ulnar flexion in its proximal joint and flexion in its middle joint.

(A and B) Proximal joint of long finger cannot abduct and middle joint is in flexion contracture of 62

(C and D) Flexor sublimis tendon was detached from its insertion, brought out in the palm, and made to fuse to the lateral band of the dorsal aponeurosis to act for the inter osseus muscle. The scar was so dense and adherent to the bone at the knuckle that a graft of deep forearm fascia was placed between tendon and bone.

Photographs taken six months later show the flexion contracture better 22 and good ability to abduct the proximal joint against the weight of a hammer She then used the hand without complaint.

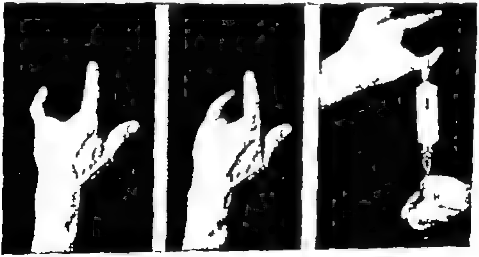


FIG. 422 Case J R. Restoration of action of intrinsic muscle

From a buzz saw injury a year previously he had little use of the little finger He could not flex or radioflex its proximal joint and lacked 55 of extension of its middle joint.

Capsulectomy increased the flexion of the proximal joint to [illegible] and severing the insertion of the flexor sublimis allowed the middle joint to straighten. The sublimis was passed from the palm through the lumbrical canal to the lateral band, substituting for the interosseus muscle.

(*Left* and *Center*) Showing good lateral control of the little finger its tip moving through an amplitude of one and seven-eighths inches.

(*Right*) Restored power of abduction of the little finger registers six pounds compared with only one in his normal hand.

Better results were obtained by placing a fine stainless steel wire stitch in the tendon, with a pull-out wire for removal in three weeks A spot for insertion on the distal phalanx is then roughened and the tendon end is held there by passing the wires on out through the skin and tying them through a drill hole in the finger nail. Great care is used to minimize trauma. Plaster splinting in the position described and including the hand is maintained for a month If the tendon be found to have rejoined, but adherent proximally, it may be sufficient merely to free it and allow it to displace proximally, preserving the insertion but placing fat beneath It is then kept relaxed by splinting When joined but not adherent it may be shortened proximally

Drop Finger at Middle Joint. When the central slip of the extensor tendon is cut opposite the middle finger joint causing drop finger, two figure-of-eight stitches of fine stainless steel wire No 35 are placed through tendon ends and skin, and an extension splint is applied. The longitudinal tear, allowing the tendon strands to separate, will then heal by itself if recent If the tear is old, the longitudinal edges are freshened and sutured by a figure-of-eight fine wire, which is carried out through the skin

A further discussion of finger drop appears in Chapter 12 under Rupture of Tendons.

Loss of extensor tendon from the back of the proximal phalanx is difficult to repair If a tendon graft is placed to join up the long extensor to its insertion on the middle phalanx it will not be successful This tendon extends also, the proximal joint, so the adjustment must be too accurate to extend both joints and the main extensor of the middle finger joint is a lateral band It is possible to extend the long extensor to the middle phalanx if the slip of insertion to the proximal phalanx be severed A separate extensor tendon, such as a proprius may be used but there is a tendency for it to slip off the joint Fowler succeeded in some cases where the skin was in good condition as follows A thin tendon graft from the extensor indicis proprius, or minimi digiti, was passed through a hole drilled across the middle of the middle phalanx The tendon was then crossed over the back of the middle joint, and each end of it was sutured into the interosseus muscle on its respective side If the interossei were injured or more power was needed, the tendons were fastened to the split sublimis tendon in the palm One of these cases that I saw had complete extension and 90 degrees of flexion in the middle joint Even if the sublimis tendon does not slip, advantage is gained in the tenodesis action by which extension of the proximal joint will extend the distal two (Fig 405)

The problem of burned fingers, in which the middle slip of the extensor tendon is gone, is difficult because there is too much dorsal scar to allow a tendon to glide. A pedicle graft is necessary In a burn case where the skin over the proximal phalanx was fortunately freely movable, Fowler s operation was successful Usually the joint, also, has been burned, so arthrodesis in a position of mild flexion is advisable

From contracture following burn the proximal finger joint may become so hyperextended that the intrinsic muscles can no longer flex the joint, but instead increase the deformity On correcting the contracture the sublimis tendon is attached to the lateral band to replace the intrinsic muscles which have been overstretched.

Summary and Conclusions

1 The intrinsic muscles of the hand are primordial, having started in the fish The hand developed before the arm Intrinsic muscles persisted down the animal phyla, and not until later did some intrinsic hand muscles develop into the long flexors and extensors (flexor profundus in reptiles and

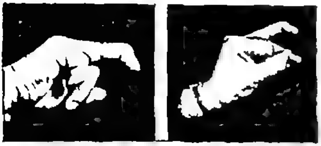


FIG. 423 Drop finger from loss of insertion of extensor tendon by severance, rupture, or of evulsion of piece of bone, often from stubbing the finger There is complaint of the finger getting in the way The illustrations show drop finger one from stubbing the other from laceration by glassware. To both, good function was restored by repairing with removable stainless-steel wire.

flexor sublimis and extensor brevis in mammals) (See Chapter 1)

2 The interosseus and lumbricalis muscles have two separate functions, depending on whether or not the proximal finger joint is stabilized in extension by the long extensor tendon (a) extension of the distal two joints of the fingers together with lateral motions of the finger, and (b) flexion of the proximal finger joints.

3 *A shift of the aponeurotic sleeve* at the base of the finger aids in determining these movements, and a volar shift of lateral bands at the middle joint makes normal movement possible.

4 In the first half of the range of flexion of the proximal finger joints, the intrinsic muscles predominate in extending the distal two finger joints, but in the last half in flexion the long extensors predominate.

5 Normal finger action depends on nice muscle balance, coordination, and synergy, each of the various intrinsic and long muscles and tendons doing its part in the consecutive motion.

6 There are different types of deformities due to loss of action of various intrinsic muscles.

7 For *loss of intrinsic muscle action* various methods of operative treatment are *valuable in restoring muscle balance* to the fingers.

INTRINSIC MUSCLES OF THUMB

ADDUCTION OF THUMB, CARPAL AND METACARPAL ARCHES

Adductors of Thumb

In ulnar nerve paralysis the loss of the *adductors of the thumb* is shown by two signs which are of particular interest. The patient cannot make a perfect O with the thumb and index finger, and the pinch between them is weak. When he attempts to do this, the metacarpophalangeal joint of *the thumb drops into hyperextension.* The same deformity is seen from loss of the abductor pollicis longus tendon. In the former case it is due to lack of flexion effect on the metacarpophalangeal joint, and in the latter to loss of ability to stabilize the metacarpal in extension Not all cases of ulnar paralysis show this, as in some the median motor nerve supply extends far enough ulnarward to flex the metacarpophalangeal joint.

Another sign of adductor paralysis is inability to scrape the extended thumb across the palm and bases of the fingers to the ulnar side of the hand. Instead, the thumb comes forward from the palm at the radial border of the index finger

In adductor paralysis the deep part of the first web is thin from atrophy of the adductor muscles. When the straight thumb *is held extended and adduction is attempted* these muscles cannot be felt to activate. Pinching of the straight thumb against the radial side of the hand is done only by the extensor pollicis longus.

Carpal and Metacarpal Arches

The arching at the carpus and the metacarpal heads is essential for grasping small round objects. It results in a tipping of the axes of the proximal finger joints, which makes the fingers converge *on flexion* and spread on extension, and greatly helps opposition of both the thumb and the little finger The arches also give strength and

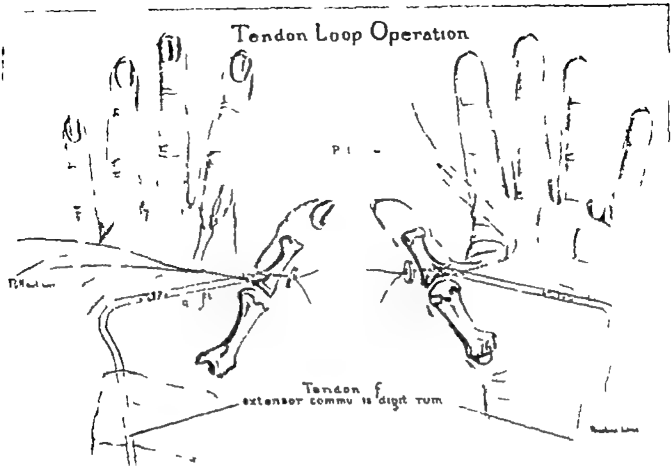


FIG. 424 In the tendon loop operation to restore adduction to the thumb the extensor communis tendon from the index finger is prolonged with a tendon graft, and then passed subcutaneously around the ulnar border of the hand and across the palm under the flexor tendons to act as an adductor of the thumb Attachment to the thumb is by fine stainless-steel wire through a drillhole to a button outside the skin. A flake of bone is chipped up at the insertion. A pull-out wire is placed so that the suture may be removed in three weeks. The stump of the extensor communis of the index finger is attached to the extensor indicis proprius to prevent rotation deformity

resiliency when pressing with the hand. Normally in opposing the thumb and little finger, the palm is cupped and the curve of the metacarpal arch is increased.

Maintenance of these arches is by the thenar and hypothenar muscles which span from the carpus to the two outside rays, and slightly by the palmaris longus Thus, in combined median and ulnar paralysis the hand is flat and the thumb is at the side

Operations to Restore Adduction to Thumb and Curvature to Carpal and Metacarpal Arches

This is needed in paralysis of both median and ulnar nerves but usually not for paralysis of the ulnar nerve alone.

Two methods are available the tendon loop operation and the tendon T operation

Tendon Loop Operation. In the tendon loop operation, to furnish adduction to the thumb, the tendon of the extensor digitorum communis to the index finger is detached, just before it spreads out over the proximal joint of the index finger, and is withdrawn at the base of the back of the hand It is elongated, by adding a free tendon graft from the palmaris longus or other tendon, and is passed subcutaneously around the ulnar border of the hand, then across the palm deep to the flexor tendons, to be inserted on the ulnar side of the base of the proximal phalanx of the thumb

The communis tendon is selected instead of the proprius, because its muscle is

stronger It is essential to attach its stump, where cut off, to the proprius tendon, so that the latter will pull symmetrically on the tendinous cap of the joint, otherwise the index finger will show deformity of rotation and adduction. A short transverse incision is used there, and also on the dorsum of the hand at the distal edge of the annular ligament. The incisions at the ulnar border of the hand and ulnar side of the thumb are midlateral

In passing the tendon around the ulnar side of the hand, it was found best not to pass it under the hypothenar muscles, because their perimysium adhered to it. A simple way of attaching the tendon to the phalanx of the thumb is to place a wire stitch in the tendon, as described in the operation for claw finger A thin flake of bone is chipped up, and under this the wires on a single straight needle are passed through a drill hole through the bone and out the skin on the opposite side of the thumb, where they are threaded through the holes of a button and tied The pull-out wire is also brought out through the skin proximally, so that the stitch wire may be removed in three weeks.

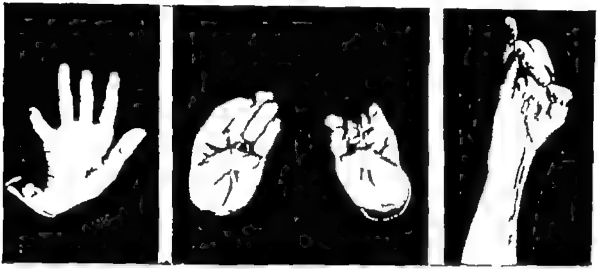


FIG. 425 Case E. W Loss of both adduction and opposition of thumb from severance of both motor branch of ulnar and motor thenar branch of median nerves, there being too great a gap in each of them for suture.

(*Left*) Limit of adduction and opposition of thumb

A pulley operation was done for opposition using the palmaris longus as motor the extensor pollicis brevis as tendon, and looping about the flexor ulnaris as a pulley

A tendon loop operation was done for adduction, looping the tendon of the extensor digitorum communis of the index finger around the ulnar border of the hand and to the adductor tubercle in the proximal phalanx of the thumb The median nerve was sutured to the five of its sensory branches.

(*Center* and *Right*) Photographs taken a year later show excellent ability to adduct and oppose the thumb. Sensation returned throughout by the eighth month.

Tendon T Operation. The tendon T operation gives strong adduction to the thumb and little finger and cups the hand, restoring carpal and metacarpal arches. (Figs. 426 and 306) It consists of one free tendon graft spanning across the palm behind the flexor tendons from the base of the proximal phalanx of the thumb to the neck of the metacarpal of the little finger One of the long flexor tendons of the forearm, such as a sublimis, is attached by a loop to the center of the cross tendon, thus forming a T On contraction of the muscle the T is drawn to a Y, drawing the thumb and fifth metacarpal toward each other and restoring the arches. The cross member lies in soft, movable tissue back of the profundus tendons and can be drawn proximalward without resistance. It does not press or pull against the deep branch of the ulnar nerve which is behind it. The cross

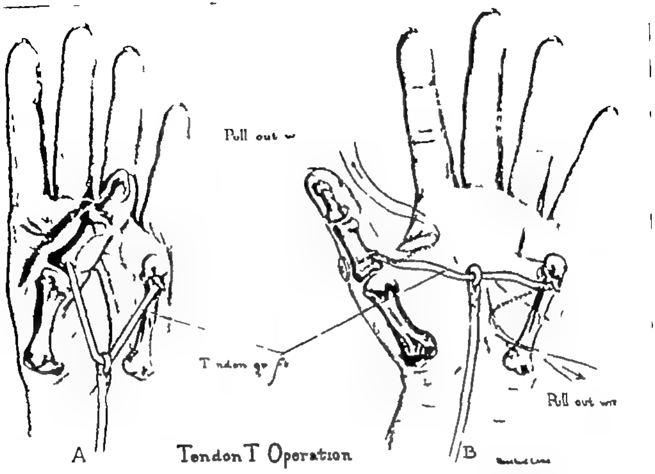


FIG 426 In the tendon T operation to restore adduction to the thumb and curvature to carpal and metacarpal arches a tendon graft spans the distance between the little finger meta carpal and the adductor insertion in the proximal phalanx of the thumb A long flexor tendon of the forearm (a sublimis or the palmaris longus prolonged by a strip of its palmar fascia) is looped over its center to form the T (B) This when in action, changes to a Y (A) adducting the thumb and curving the arches. Attachments to bone are made as in Fig. 356.

part of the T comes in full flexion as far proximally as the carpus, and the angle of the Y thus formed is then 40°

The fifth metacarpal is exposed in its ulnar volar aspect. One end of the cross tendon is fastened to it under a chipped up flake of bone, as described for the thumb in the tendon loop operation, the button resting on the skin of the back of the hand over the dorsoradial aspect of the fifth metacarpal, where the wires come through The palm is opened by a small L-shaped incision paralleling the creases The tendon is passed across through the palm behind the flexor tendons, and is made to emerge through a small lateral incision over the ulnar aspect of the base of the proximal phalanx of the thumb Here it is similarly attached by passing the wires through the phalanx and thumb to a button on the opposite side, and placing a pull-out wire. The tendon should be slack when the hand is fully spread, as grafts shrink a little For the cross member, the tendon of the extensor pollicis brevis, which is already attached to the thumb, may be used. The long flexor tendon is then looped around the center of the cross tendon, imbedding it in and suturing it to itself one stitch is placed to keep it from sliding along the cross tendon In place of the sublimis tendon, the palmaris longus tendon with its prolongation of palmar fascia, or any other flexor tendon that is available, may be used.

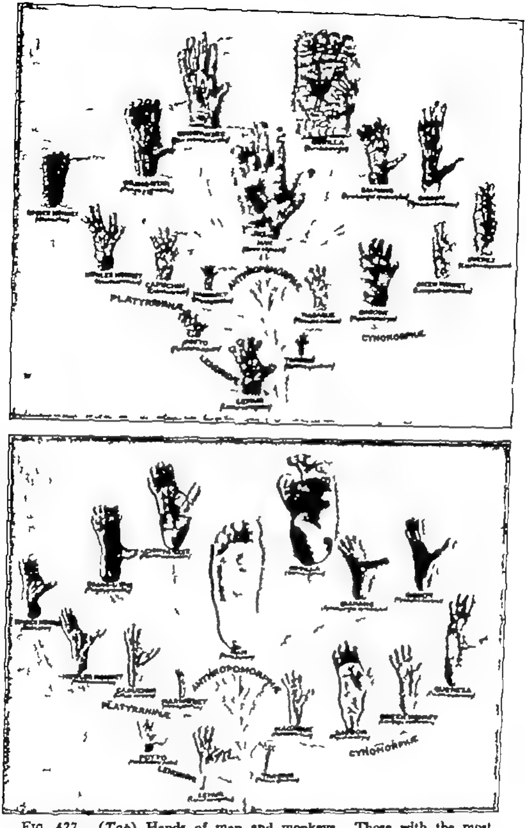


FIG. 427 (*Top*) Hands of man and monkeys. Those with the most opposable thumbs are, in order man, gorilla baboon chimpanzee, and orangutan. The more ground dwelling is the monkey the better developed is the opposable thumb the more arboreal the less thumb it has. The more prehensile is the tail as in new world monkeys the less use the animal has for a thumb until the spider monkey has none at all.

(*Bottom*) Feet of man and monkeys. In man the feet are used entirely for locomotion, so that the hallux has entirely lost the power of opposition and the pollex has *developed it. All monkeys have an opposable hallux far* better developed with the exception of the gorilla and the baboon than is the pollex. (Courtesy of the American Museum of Natural History New York, N Y., and Jour Bone and Joint Surg.)

Opposition of Thumb

Discussion

A great asset to man is the opposable thumb The hand so useful to all and the livelihood of the manual worker owes much of its efficiency to this pincer action of the thumb

Opposable digits are not new in Nature. Most birds have them The digits of the African chameleon directly oppose each other around a branch and as far back as the crustaceans there are opposing claws of crabs and lobsters

In mammals the opposable thumb is found only in the primates and starts with the lowest forms of them, the lemurs The more arboreal is the monkey, like the gibbon, and the more developed its prehensile tail, as in the Western Hemisphere, the smaller and less opposable is its thumb, so the spider monkey is even thumbless A

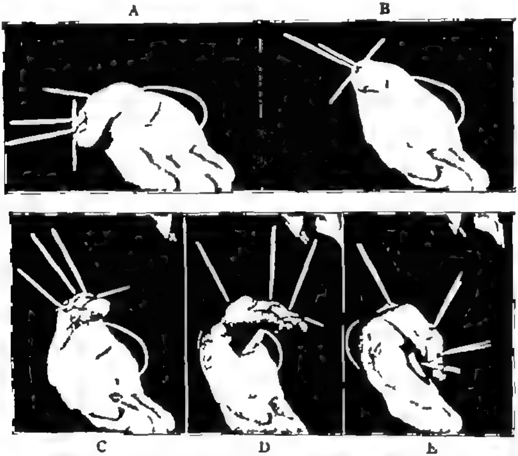


Fig 428 The successive positions assumed by the thumb in transcribing its normal forward arc of opposition. The toothpicks—one placed crosswise and parallel with the nail and three each vertical to a separate segment of the thumb—are to show more graphically the angulatory and pronatory thumb movements.

(A) The thumb starts at the side of the hand. The nail is at a right angle with the palm, and the vertical toothpicks are in line with each other

(B) After the first third of the arc has been traversed, the thumb commences to pronate.

(C) The greatest pronation is between (B) and (C)

(D) Position of full opposition with the thumb well forward from and opposite the base of the long finger angulated toward the ulna, and with the nail parallel with the palm. Note the degree of pronation shown in the relative positions of all four toothpicks.

(E) The thumb now past the position of opposition, is completing its arc and approaching the base of the little finger (Courtesy Jour Bone and Joint Surg., 20 272 No 2 April, 1938)

hand without opposition of the thumb has been called "ape hand," but this is an injustice to the apes as in their hands opposition is well developed and it is even more so in their great toes. In man locomotion has been confined to the feet, leaving the hands free to develop handiwork. The pollex has thus become more opposable and the hallux has lost its power of opposition.

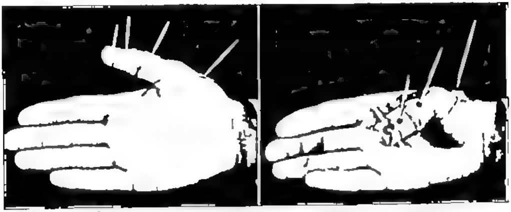


FIG. 429 Views from the front with the thumb at the side of the hand and in full opposition. Note the degree of pronation of the segments of the thumb made graphic by toothpicks. The nail rotates through 90 The greatest pronation occurs at the metacarpophalangeal joint. (Courtesy Jour Bone and Joint Surg., 20 273 No 2 1938.)

Definition and Description

The term "opposition" is from the Latin "oppositio" meaning opposite. It implies opposite and far apart like the opposite points in a circle. In astronomy when two heavenly bodies are 180° apart they are said to be in opposition

The thumb to be in true opposition must not only be opposite the fingers and far forward from them, but it must also be by rotation diametrically opposite to them—that is, with the pulp of the thumb facing that of the fingers and with the thumbnail parallel to the palm or volar surface of the fingers. Also, in the motion of flexion and extension, the thumb and the opposing digits should move in exactly opposite directions to each other

Merely placing the thumb into apposition—that is, in contact with the fingers—or drawing it into the palm is not opposition, nor is it when the thumb fails to rotate and its nail is still at a right angle to the palm

Motion of Thumb and Mechanism of Opposition

Normally the thumb can touch the palm in its distal and radial margins, as well as all of the fingers over most of their surfaces, although this is increasingly less possible on their dorsal and ulnar aspects as the thumb reaches from the index to the little finger The thumb can also pass backward over the radial border of the palm to reach the plane of the dorsum of the hand From here it can abduct from the hand to about a right angle and then sweep forward from the hand in a semicircle until it touches the base of the little finger Let us observe the thumb in its excursion through this forward arc.

At the start, the thumb and thenar eminence form a cone protruding laterally from the hand. When midway in the path of the semicircle, this cone projects forward from the hand, and the thenar crease is folded to a right angle. If we watch the thumb again through this arc, we will see that at the start the nail is at a right angle to the palm, and the thumb bones are in a straight line as seen from behind In traversing the semicircle these relations are maintained

A B C D E F

FIG. 430 Case S L. Median palsy and loss of flexor tendons of digits resulting from a severe infection starting in thumb

(A) Limit of opposition of the thumb

(B and C) Limits of extension and flexion of digits.

The median nerve was sutured to all its branches including the motor thenar Four inch tendon grafts from extensors of toes were used to join up flexor tendons of thumb and fingers.

(D) Return of opposition from suture of median nerve to its motor thenar nerve two years previously

(E) Return of flexion of thumb and extension of fingers.

(F) Degree of flexion of fingers.

and a certain strain is felt in the thenar eminence until, as the first third is completed the strain leaves, the nail starts to rotate in pronation, and the proximal phalanx angulates radially on the metacarpal As the change occurs, the muscles in the radial half of the thenar eminence conspicuously spring into action and continue the motion. The strain occurs when the adductors are fully stretched by the long extensors of the thumb The adductors insert on the ulnar side of the proximal phalanx and, when under tension, tend to supinate, but are opposed by the muscles attached to the radial side of the phalanx—principally the outer head of the short flexor The latter pronates and, after pronation is started, also angulates the phalanx radially The strain is relieved just as the adductors are relaxed and the short flexors have their way Throughout the arc the long extensors maintain the necessary stabilization in extension of the three joints of the thumb

The motion of opposition takes place in the radioscaphoid, intercarpal, carpometacarpal, and metacarpophalangeal joints. This motion is of two types—angulatory and rotary—and all of these joints contribute to each The carpometacarpal joint furnishes most of the angulatory motion and the metacarpophalangeal joint most of the pronatory motion The sum of the angulatory movement in opposition is shown in the distal segment of the thumb which angulates through an arc of about 120°, and the sum of the pronatory movement is shown in the plane of the thumbnail which rotates 90 from a position at a right angle to the palm to one parallel with it See Fig 428 and Fig 429 Toothpicks are attached to the skin the better to show the movements in each segment of the thumb

The scaphoid, greater multangular, and bones of the thumb constitute one ray in this motion of opposition, and as this ray inclines forward (the scaphoid and lesser multangular gliding on the capitate), the carpal arch is increased. This is readily demonstrated by the inability to oppose the thumb when the carpal arch is prevented from arching The arching is produced largely by contraction of the thenar muscles

which are attached to the transverse carpal ligament. The palmaris longus aids in this The metacarpal is angulated and pronated on a saddle joint *principally by the oppo*nens pollicis aided somewhat by the abductor pollicis longus and the outer head of the flexor pollicis brevis. The proximal phalanx is angulated and pronated mostly by the outer head of the flexor pollicis brevis acting on a ball-and-socket joint.

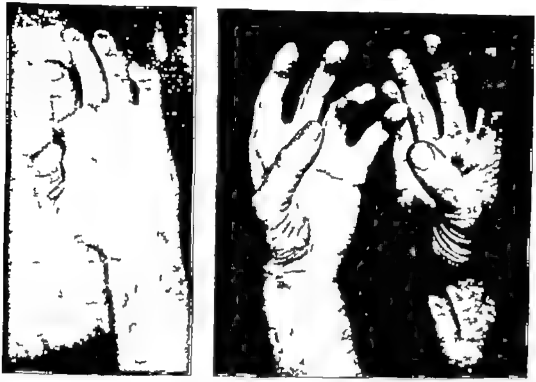


FIG. 431 Case E. S Restoration of opposition of the thumb by suture of the median nerve at the wrist.

(*Left*) From laceration at the wrist, both median and ulnar nerves and several tendons were severed, resulting in clawhand with atrophy of the thenar muscles and complete loss of opposition and adduction of the thumb.

(*Right*) Two years later function of the intrinsic muscles had been restored by suture of the median and ulnar nerves. The thenar eminence and other intrinsic muscles, as well as the ability to oppose the thumb had been restored so that the patient was able to resume the practice of dentistry (Courtesy Jour Bone and Joint Surg., 20 276 No 2 April, 1938)

The main antagonist to opposition is the extensor pollicis longus although this muscle also aids in the motion by its effect along *with the extensor pollicis brevis and the ab*ductor pollicis longus in stabilizing the joints of the thumb in extension.

With the wrist dorsiflexed and the thumb in opposition the cleft open for grasp between the thumb and the palm is then in direct line with the forearm, as it should be. Opposition aids in forming a circle with the thumb and index finger and an ellipse with the thumb and little finger

The degree of opposition may be expressed by the distance which the pulp of the thumb reaches in front of the base the long finger and also by the pronato angle or the plane the nail makes with t palm as compared in each instance of the measurements in the normal hand. Thu opposition in a hand may be expressed one inch and 45° of angle, compared wi three inches and an angle of zero, whic are the similar measurements taken fc comparison in the other or normal hand.

Causes of Loss of Opposition

Lack of function of the median nerve o its motor thenar branch, or the loss of th thenar muscles supplied by the mediar

nerve, deprives a thumb of opposition Cord lesions, as in poliomyelitis, or displaced disc between C 6 and C 7 selectively result in loss of opposition Other causes are flexion contractures from cicatrix on the dorsum of the hand, a transverse scar across the middle of the dorsum of the hand, cicatrix between the first two metacarpals, adhesions holding the tendon of the extensor pollicis longus flathand from flat splinting and injury of the joints or arthritis bordering the trapezium Compression of the median nerve between the lower edge of the carpal ligament and radius produces atrophy of the thenar muscles as seen after malunion of Colles's fracture, dislocated semilunar or fracture of the scaphoid Local ischemic contracture of adductor muscles prevents opposition

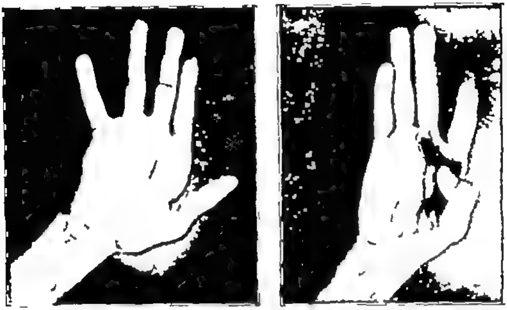


FIG. 432 Case W W Extensive laceration of the hand and wrist 18 months previously in which the median and ulnar nerves and several tendons were severed

(*Left*) Complete thenar atrophy and loss of adduction and opposition of the thumb and loss of abduction of the index finger

(*Right*) Extensive repair of nerves and tendons was done. Without waiting for the nerves to regenerate the tendon of the extensor indicis proprius was sutured to that of the first interosseus muscle with restoration of abduction of the index finger A pulley operation was then done on the thumb, in which the flexor carpi ulnaris was used as the motor power and a slip from it was used to construct the pulley The tendon of the extensor pollicis brevis was withdrawn from the arm and transferred subcutaneously across the thenar eminence through the pulley and sutured to the flexor carpi ulnaris. In the photograph, taken only two months later the tendon can be seen drawing the thumb two inches in front of the base of the index finger (Courtesy Jour Bone and Joint Surg., 20.277 No 2 April 1938)

Methods of Restoring Opposition

Opposition may often be restored, depending on its cause, by nerve suture, by excision of the cicatrix binding the first and second metacarpals, dorsal skin, or of adhesions of the extensor pollicis longus tendon, or by a bone or joint operation Of the latter there is rotary angulatory osteotomy of the metacarpal, carpal wedge osteotomy in case of ankylosis of the carpus, and bone graft bridging of the first two metacarpals In 24 cases the author has sutured the motor thenar branch of the median nerve to restore opposition The motion returned in about 13 months. In a series of the author of 108 repairs of the median nerve by suture, opposition has been restored in 66 per cent.

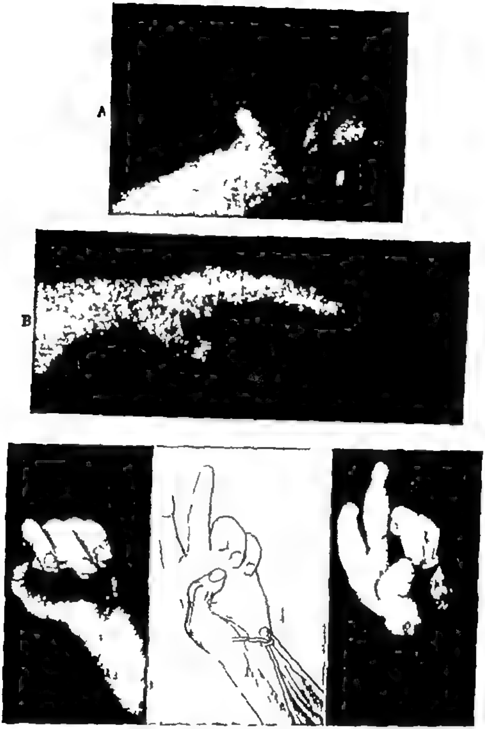


FIG. 433 Case M. V., aged 20 Infantile paralysis at the age of four left her with paralysis of the extensors of the fingers and of the thenar muscles. She had no power of extending the fingers as shown in (A) and no ability to oppose the thumb against the fingers, (C) and (A) Flexion of the thumb was very weak.

Operation. The tendon of the extensor carpi radialis brevis was transferred to pull on the tendons of the extensor communis digitorum, thus restoring the power of extension of the fingers, as shown in (B) The tendon of the flexor sublimis digitorum of the ring finger was transferred in its insertion to the tendon of the flexor longus pollicis thus giving strength to the motion of flexion of the thumb. The tendon of the palmaris longus, together with its extension, the palmar fascia was passed through a pulley at the pisiform bone made by a free tendon graft from an extensor tendon of the toe, and passed on subcutaneously and inserted into the tendon of the extensor longus pollicis. (D) Good power of opposition was obtained as shown in (E) (Courtesy Surg., Gynec., and Obstet., 39:275 Sept., 1924)

When the nerve or thenar muscles are irreparable, tenoplasty by the pulley operation will restore good opposition. As a preliminary to all tendon work, the joints and all restraining structures, if necessary, must be made free so the thumb will assume the required position without any strain.

Two Essential Principles of Tenoplasty for Opposition

1 The tendon from its insertion in the thumb should pass subcutaneously in the direction of the pisiform bone, so that it will pull the thumb in the correct direction.

2 The insertion of the tendon should be on the dorso-ulnar aspect of the base of the proximal phalanx of the thumb, so as to restore the pronatory component. The tendon should pass directly over the summit of the metacarpophalangeal joint, not distal to it.

To make the tendon pull toward the pisiform bone, either a tendon pulley is constructed there or the tendon is looped around the distal part of the tendon of the flexor carpi ulnaris. There will then be a similar arrangement to that found anatomically in the omohyoid or the tensor veli palatini muscles.

The first case in which the author used these principles was reported in Surgery, Gynecology, and Obstetrics in September, 1924. His series of 124 cases has convinced him of the correctness of these principles. Many other methods have been reported by the use of which excellent results have been claimed. From the illustrations in these reports, however, it is evident that the conception of true opposition was not as expressed here. No operation where the tendon passes under the transverse carpal ligament can possibly produce true opposition, as the tendon does not pull in the right direction. It merely pulls the thumb into the palm and not out forward from it.* Also if a tendon is used for opposition, it should be for that function alone and should not have two insertions each for a different function. Otherwise there will not be free and independent action in each of the two functions. If the flexor is used, the thumb cannot be flexed without opposing. The muscle transferred should be adequate in strength and its original function, if important, should not be sacrificed.

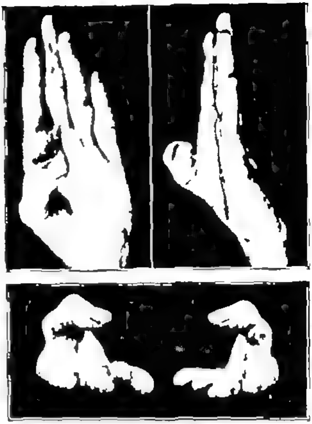


FIG. 434 Case P C. A burn from a bottling machine destroyed the thenar eminence. This was covered by a pedicle skin graft.

The ability to oppose the thumb was restored by a tendon-transfer pulley operation. The tendon of the extensor pollicis brevis was detached at its muscle, withdrawn through an incision at its insertion and then passed subcutaneously across the thenar eminence toward the pisiform bone. The tendon of the palmaris longus was detached at its insertion, looped about the tendon of the flexor carpi ulnaris for a pulley and then sutured to the tendon of the extensor pollicis brevis.

(*Top*) Good opposition restored. The tendon pulling beneath the skin is apparent.

(*Bottom*) Showing loss of the thenar eminence. (Courtesy Jour Bone and Joint Surg., 20:279 No 2 April 1938.)

* In some cases of poliomyelitis, as Ober has suggested, the transverse carpal ligament is so lax that a tendon passed under it might pull the thumb toward the pisiform bone.

Other Methods Reported

With these principles in mind, the author wishes to mention briefly the methods previously reported.

Methods in Which Tendon Is Passed Under Transverse Carpal Ligament. Krukenberg split the flexor digitorum sublimis tendon of the long finger and inserted it in the radial half of the first metacarpal

Roeren did the same with the flexor digitorum sublimis tendon of the ring finger

Ney used the tendon of the extensor pollicis brevis detached above, and, after passing it under the transverse carpal ligament, joined it to the tendon either of the palmaris longus or of the flexor carpi radialis.

Royle transferred the flexor sublimis tendon, still under the carpal ligament, down through the sheath of the thumb flexor, and inserted the two branches, one on the back of the proximal phalanx and the other on that of the metacarpal

T C. Thompson modified Royle s method by passing the sublimis tendon from the lower border of the carpal ligament to the thumb subcutaneously instead of through the flexor sheath.

Lyle employed the same method but, in addition, combined it with Steindler's operation on the flexor pollicis longus tendon.

Methods Using Flexor Pollicis Longus Tendon and Also Keeping *Tendon* Beneath Transverse Carpal Ligament. Steindler split the distal end of the flexor pollicis longus tendon in two and detached the radial half from its insertion, passed it around the radial side of the thumb, and reinserted it at the back of the base of the proximal phalanx.

Silfverskiöld risked the use of the whole flexor tendon of the thumb, transplanted it around the radial side of the thumb, and inserted it at the base of the proximal phalanx.

Von Baeyer freed the insertion of the flexor pollicis longus, passed it around the radial side of the thumb, and reinserted it at its original insertion.

Methods Using Extensor Tendons. Jahn passed the extensor tendon of the third digit around the ulnar border to the volar

FIG. 435 Case A. H. (*Left*) The median nerve had been severed at the wrist and was sutured three years previously but without return of the thenar eminence or ability to oppose the thumb

(*Right*) A tendon transfer pulley operation promptly restored ability to oppose the thumb as shown in the hand with the atrophied thenar eminence and the sleeve rolled up. The flexor carpi ulnaris tendon was split in two near its insertion. One half was used to make a pulley and the other was detached at its insertion and prolonged by a free graft from the tendon of the *palmaris longus*. *This was passed through the pulley across* the thenar eminence subcutaneously over the dorsum of the proximal joint of the thumb and attached by a drillhole to the base of the proximal phalanx at its dorso-ulnar aspect. (Courtesy Jour Bone and Joint Surg., 20.279 No 2 April, 1938)

side of the hand and inserted it into the first metacarpal He repaired the defect with a free fascial transplant.

Cook's operation, as described by Taylor, consisted of passing one of the extensor tendons of the little finger around the wrist subcutaneously and inserting it into the first metacarpal

Miscellaneous Methods Huber and Nicolaysen used the abductor of the fifth digit and fastened it to the first metacarpal

Howell severed the flexor pollicis longus tendon at the wrist, slit the thumb from end to end, lifted the tendon from its bed, and passed it around the radial side of the thumb It was then brought subcutaneously across the thenar eminence and resutured to itself in the radial side of the wrist.

Camitz inserted the tendon of the palmaris longus with some of the palmar fascia on the lateral side of the metacarpophalangeal joint of the thumb

Kortzeborn used a fascial sling to fix the thumb in opposition, did a plastic operation on the palm and lengthened the extensor tendons.

Spitzy, and also Baldwin, performed an arthrodesis on the carpometacarpal joint of the thumb

Foerster planted a 3-cm. bone graft from the tibia between the first two metacarpals

Technic of Operation Advocated

Joints and Contractures Freed As in all tendon operations, the joints and tissues must be mobile enough to allow the full movement. Flexion contracture on the dorsum or between the two metacarpals should be relieved, including if necessary capsulectomy of the carpometacarpal joint, being careful not to cause dislocation. If the deformity is too fixed, a preliminary rotary, angulatory osteotomy can be done on the metacarpal.

Two Essential Principles. If the two main essential principles, mentioned above

Fig. 436 A splint of adhesive plaster to hold the thumb in position of opposition. A small pad protects the skin The resultant of pull by the two arms of adhesive is in the direction of the pisiform bone. This splint is useful in protecting paralyzed thenar muscles and newly placed tendons and in bending stiffened joints into this functioning position including increasing the carpal arch. (Courtesy Jour Bone and Joint Surg 24.275 1938)

as 1 and 2, are adhered to, one has quite a varied choice in selection of muscle and tendon and in construction of the pulley, depending on which are available or advantageous in the particular case of reconstruction Each hand is a problem in itself, and, as the parts injured differ, so we must adapt our procedure to the available material providing we adhere to these two simple principles—namely, direction of pull, and correct insertion to give pronation.

The insertion should be into the ulnar side of the base of the proximal phalanx. The tendon should pass directly over the dorsum of the metacarpophalangeal joint in the great circle. A common error that draws the thumb into flexion is to cross just distal to the joint. The tendon should then pass subcutaneously to a pulley just above the pisiform bone.

To supply a motor, a tendon, and a pulley, any of the following may be available

Motor For motor power, we may use the flexor carpi ulnaris, the palmaris longus, the flexor digitorum sublimis of the ring finger, or any available long flexor muscle. The extensor muscles are rather weak for this purpose, and their course is long, thus presenting opportunities for the formation

of adhesions. However, the extensor carpi ulnaris and extensor carpi radialis brevis are strong, and prolonged with a tendon graft give good opposition without the need of a pulley if made to cross around the ulnar border of the forearm

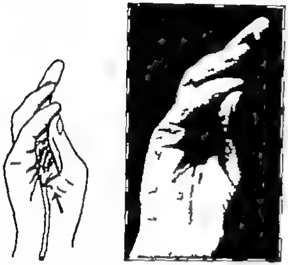


FIG. 437 Case S P Restoration of opposition of the thumb by suture of the tiny motor thenar branch of the median nerve. (*Left*) In this case the nerve was severed by surgical incision for drainage of the thenar space which resulted in atrophy of the muscles and loss of opposition. (*Right*) The photograph was taken 13 months later and shows the well restored thenar eminence and restoration of ability to oppose the thumb (Courtesy Jour Bone and *Joint Surg., 24 275 1938*)

Tendon. In regard to tendons, the extensor pollicis brevis is excellent as it already has the correct insertion, and also will retain its original function and can be sutured to another tendon just proximal to the pulley at the pisiform bone. Also the palmaris longus can be prolonged sufficiently by using its prolongation, the palmar fascia, or any tendon desired can be pieced out by a free tendon graft either from the palmaris longus tendon or from any other tendon that may be available. The tendon of the sublimis of the ring finger may be looped around the flexor ulnaris and attached directly to the proximal phalanx of the thumb If severed too short or too long, deformity of the ring finger results. If the muscle of the sublimis is used for a motor, the tendon may be activated above the wrist by joining it to the sublimis tendon of long finger The ulnari may pull directly

Pulley For the construction of a pulley at the pisiform bone, a free tendon graft either from the palmaris longus or from any other available tendon can be looped through the short muscle and tendon attachment to the pisiform bone and sutured to itself, so that it forms a circle 2 cm. in diameter The sutured junction is then slipped around until it is within the muscle.

Another method of making a pulley is to use one-half the thickness of the flexor carpi ulnaris tendon, severing one of the halves high and suturing this free end to the ligament of the pisiform bone to complete the loop

Similarly, the tendon of the palmaris longus can be severed 4 cm above its insertion and made to act as a loop or pulley by suturing it into the pisiform ligamentous tissue, leaving its original insertion intact.

Instead of constructing a pulley, one can pass the tendon used around the flexor carpi ulnaris tendon and on to its insertion in the phalanx of the thumb The flexor carpi ulnaris then aids in the opposition.

Examples. For the sake of clarity, a few concrete examples of the technic are shown in Fig 438 A–F

In the reconstruction there may be available some tendons of the long extensors of the toes or of the palmaris longus of the other arm With a free graft of one of these, a pulley can be made at the pisiform bone The tendon of the palmaris longus is detached at its insertion and prolonged by a free tendon graft passed through the pulley and then subcutaneously across the thenar eminence over the head of the metacarpal to be inserted through a drill hole in the dorso-ulnar aspect of the base of the proximal phalanx. Another method is to detach the tendon of the extensor pollicis brevis high, draw it out at its insertion, and then pass it subcutaneously across the

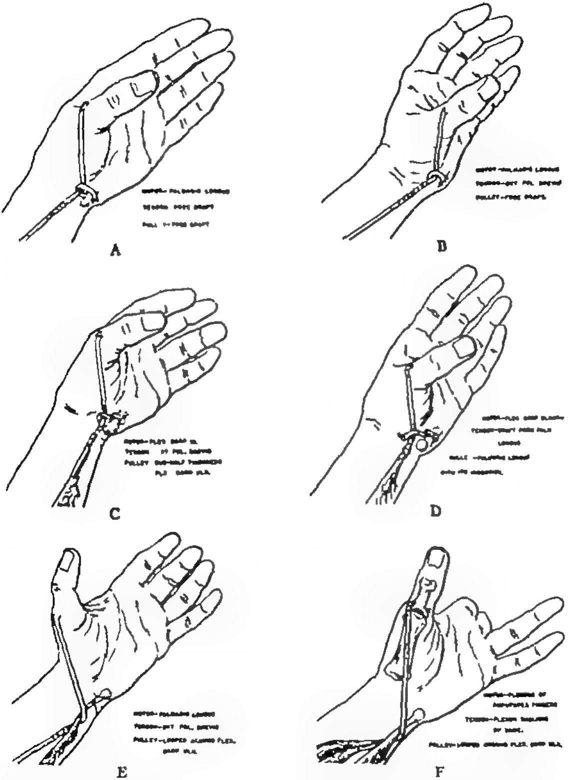


FIG. 438 · Operation advised to restore ability to oppose the thumb The two essential principles are (1) The tendon should pull in the right direction namely subcutaneously diagonally across the thenar eminence toward the pisiform bone to angulate the thumb forward and toward the ulna (2) the insertion of this tendon should be into the dorso-ulnar aspect of the base of the proximal phalanx so as to pronate the thumb Then one may use whatever seems best in the individual case for motor power tendon and pulley These drawings illustrate what muscle and tendon material may be used and ways of constructing the pulley (Courtesy Jour Bone and Joint Surg., 20 274 No 2 April 1938)

A

B C

FIG. 439 Case R. F A porcelain faucet lacerated the thenar eminence, damaging the motor thenar branch of the median nerve beyond repair and thus paralyzing the abductor and opponens pollicis muscles, so that the patient could not oppose the thumb. The flexor tendon and the two volar nerves of the thumb were also severed. Four months later the flexor pollicis longus tendon was repaired by a free graft from the palmaris longus tendon, and the two sensory nerves were sutured. A tendon-transfer pulley operation was done to restore opposition. The tendon of the extensor pollicis brevis was detached at its muscle, withdrawn near its insertion and then passed subcutaneously across the thenar eminence. Here it was passed through a pulley made from a free graft of the palmaris longus and was sutured to the tendon of the flexor carpi ulnaris which was detached from its insertion for the purpose.

(A) Showing the ability to oppose the thumb to two inches in front of the base of the ring finger and two and one half inches in front of that of the long finger

(B) The pronation and forward position gained.

(C) Atrophy of the thenar eminence. The original function of the flexor carpi ulnaris muscle has not been lost. (Courtesy Jour Bone and Joint Surg., 20 280, No 2 April, 1938)

thenar eminence to the pisiform bone. Here it is passed through the pulley and then sutured to the distal end of the tendon of the flexor carpi ulnaris The flexor carpi ulnaris muscle is quite strong, and, if it is used to give the thumb opposition, its normal function of ulnar palmar flexion is not lost. Also, if the extensor pollicis brevis is used, the function of extension of the thumb is not lost

Tenodesis Operation for Opposition In cases with insufficient musculature which still retain the power to dorsiflex the wrist, as in poliomyelitis or paraplegia between C 6 and C 7, the tendon, instead of being passed through a pulley, may be attached to the ulna 1½ inches above the wrist Then, by automatic movement, dorsiflexion of the wrist will cause the thumb to oppose. (See Chap 9)

Splinting for Opposition. A useful adhesive strapping to maintain opposition of the thumb is shown in Fig 436 Another method is to use a fingerless glove and place a strap with a buckle running from the region of the pisiform bone to over the proximal joint of the thumb Still another is to place on the hand a rubber glove of the opposite hand thrusting the thumb into the little finger of the glove Trim off the parts of the glove not used The knuckle bender splint will draw the thumb into opposition

Conclusion

The opposable thumb is valuable to man A thumb in true opposition is not only opposite the fingers, but it is far forward from them and is rotated, so that the pulp faces that of the fingers and the nail parallels the palm Any tenoplasty to produce this must adhere to two essential principles. The tendon must pull subcutaneously in the right direction toward the pisiform bone and it must be inserted in the dorso-ulnar aspect of the base of the proximal phalanx of the thumb, to give pronation This may be accomplished by using any of various muscles for motor power, and for the tendon either the extensor pollicis brevis tendon or any one of various tendons prolonged by tendon grafts The tendon used is made to pull in the right direction either by passing it through a tendon pulley constructed at the pisiform bone or by passing it around the tendon of the flexor carpi ulnaris.

Bone Operations to Restore Opposition to Thumb

These restore only the position but not the movement of opposition and are done only as a final resort when repair by nerve or tendon transplant is impossible.

Metacarpal Osteotomy When the direction of the thumb metacarpal is lateral and the carpometacarpal joint resists movement, a rotary angulatory osteotomy is done on the base of the metacarpal This bone is uncovered in its proximal half, stripping the outer thenar muscles from the shaft enough for severance, with chisel and anvil or with rotary saw The thumb is rotated and angulated to the position of opposition, a small wedge being removed to make the bones fit. A key bone graft is inserted into a slit in each to maintain rotation, and a cast is applied at once or later Oblique pinning across the fracture line or double crossed pinning between the first two metacarpals stabilizes in the correct position

Carpal Osteotomy In case of fusion of the carpus, a wedge osteotomy is done on the radial part to restore the carpal arch and place the thumb in opposition.

Graft Bridging Metacarpals. Bone bridging between the first two metacarpals, first done by Foerster and later by Allen and Thompson, is excellent for certain cases which are not suitable for tendon transplant. These include paralytic cases with insufficient musculature, spastic cases with adduction contracture, and traumatic and postinfection cases where the cleft between the first two metacarpals or the joint is too tightly contracted by scar to allow opposi

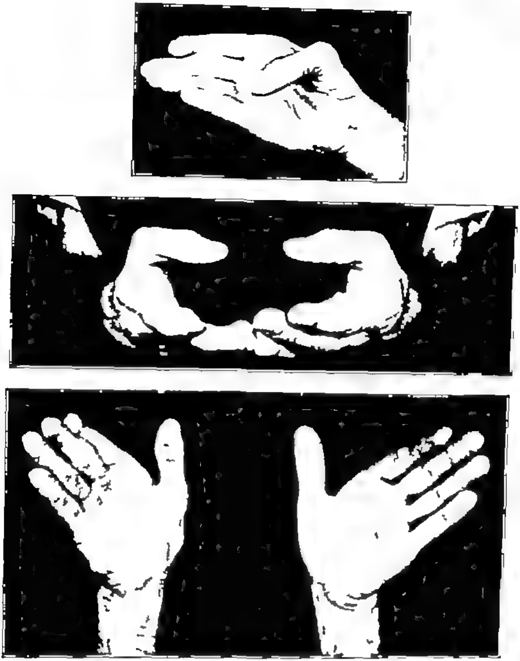


Fig. 440 Case T T Ability to oppose the thumb was lost by a wide excavation of a dado saw through the thenar eminence which destroyed beyond repair the muscles and motor thenar branch of the median nerve.

Ability to oppose the thumb was regained by a tendon-transfer pulley operation, using the flexor carpi ulnaris muscle for the motor power The tendon of the extensor pollicis brevis, which had been withdrawn from above was passed subcutaneously across the thenar eminence and through a pulley at the pisiform bone. This pulley was constructed from a free tendon graft of the palmaris longus and was sutured to the tendon of the flexor carpi ulnaris. The latter was detached from its insertion at the pisiform for the purpose, but did not lose its function as is shown in the bottom illustration. Opposition of the thumb was restored as shown in the top and middle illustrations. The atrophy of the thenar eminence shows in all three pictures. (Courtesy Jour Bone and Joint Surg., 20 281 No. 2 April, 1938.)

tion If this cleft is cleaned out surgically, the contracture will recur, so here a bone-graft spreader that will hold the thumb rigidly in opposition is needed Through a dorsal incision locating and sparing the radial artery, a measured flat bone graft from the tibia is shaped with a flat projection at each side to fit into slots in the two metacarpals as they are held apart in the position of opposition It is covered by interosseus muscle and the hand is put up in plaster Another method is to shape a triangular bone graft and wedge it into the angle between the first two metacarpals temporarily pinning it in place Position of opposition may be maintained by double crossed pinning of the first two metacarpals or by placing a stainless steel wire with buttons and shot so it will draw the metacarpal head toward the pisiform. The pulps of the first three digits may be fastened together by one stainless steel suture the object being to maintain the thumb in a position of moderate opposition with its metacarpal in a plane almost at a right angle to the palm

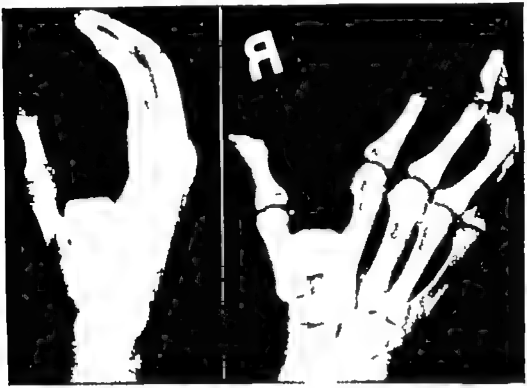


FIG. 441 (*Left*) A flat bone graft from tibia has been fitted into slots in metacarpals, with thumb in position of opposition. (*Right*) Appearance five years later (Courtesy Thompson Charles F., in Jour Bone and Joint Surg 24 908 No 4 Oct., 1942)

LOSS OF THUMB, METHODS OF REPAIRING

A hand without a thumb is so crippled that when possible some equivalent should be furnished. Prostheses, because they are insensitive, are discarded, but a thumb surgically improved or reconstructed will be used, and often with considerable function Much depends on whether or not the metacarpal and muscle attachments are present, because they furnish movement and also provide a short thumb or base upon which to build, greatly simplifying the problem.

Essentially we should provide a digit standing off from the hand in the position of opposition so the fingers can work against it. The fingers move through a certain zone so the thumb should be placed there too so they can work against it. The fingers can move laterally as they flex about

FIG 442 From a gunshot wound there was a fracture dislocation at the base of the thumb metacarpal and the thumb was held by cicatrix tight to the side of the hand. The thumb metacarpal was inserted into the trapezium and after the mass of intervening cicatrix was excised, the first two metacarpals were spread and held so by bone graft. To maintain correct position of opposition, the pulps of the first three digits had been sutured together (Courtesy of Maj John W Littler Cushing General Hospital, U.S.A.)

1½ inches This allows them to work against a properly placed thumb or to flex past it. Too frequently the thumb is reconstructed in a position outside of this zone in which case it will atrophy from disuse There should if possible, be prehensile action between thumb and fingers either by movement of fingers or of fingers and thumb, and this to be practical should be strong enough for work. In additio position, motion, and prehensile ability new thumb should have sensation an durable. The quality of sensation sh if possible, be to the degree that g stereognosis Only hand skin with its n ral specialized touch corpuscles and nat nerve connections will do this, not abd nal skin. Wherever possible, by a zig flap exchange with pedicle skin, any rem ing hand or thumb skin with its ne supply should be placed to cover the en tactile area of the thumb or any digit. following are various methods for rec structing thumbs or their equivalent.

PHALANGIZATION

A thumb which is too short is made r tively longer and freed for independent tion by deepening the cleft between it a the hand. The term also applies to sp ting up between the metacarpals of a digits in the hand so that the metacarp are phalangized. Phalangization is prac cal and successful. The presence of least most of the metacarpal is essenti In deepening the cleft between the thu and hand, the adductors of the thumb a the first dorsal interosseus muscle are the way With a blunt instrument these a stripped down the first and third met carpals to yield a cleft and still have a litt action If the cleft is made too deep, the will be insufficient power of adduction. compromise is preferred A deep zigz plastic in the cleft is usually satisfactor If skin is scarce a flap of dorsal skin is la across the cleft to establish its depth. Th volar skin is then wrapped over the denude area of the new thumb and a small ski graft is placed on the hand side of the cleft A more durable cleft is made by slidin over this area a flap of dorsal skin an free grafting the area on the dorsum s denuded

When the index finger is gone and a stump of the metacarpal remains, it will be

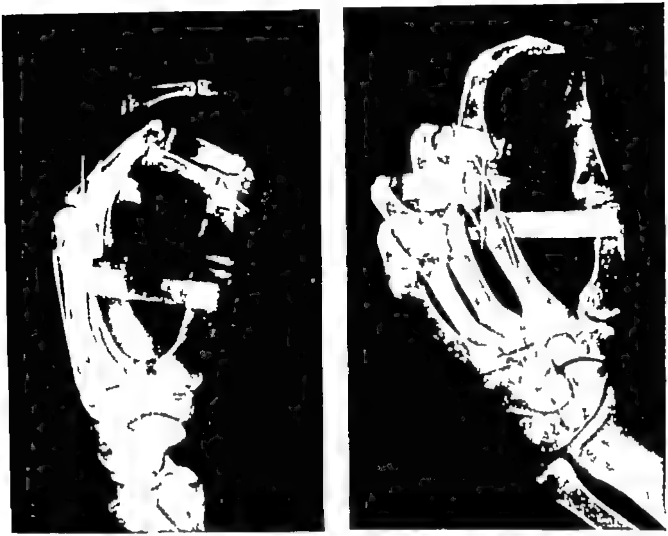


FIG. 443 (A and B) The hand was useless due to injury of three major nerves and Volkmann's contracture locally in the hand. The proximal finger joints were fixed flexed and ulnar deviated and the thumb was tight to the hand. To restore mechanism for pinch, the proximal joint of the index finger was fused in 30 degrees of flexion holding by crossed wires the thumb was spread and fixed in opposition by a bone graft, contacting its tip with that of the index finger by a temporary suture. (Courtesy of Maj John W Littler Cushing General Hospital, U.S.A.)

a painful obstacle in the cleft necessitating removal obliquely near its base. This gives a wider cleft and more skin for coverage

Several aviators lost all digits at the metacarpophalangeal joints due to loss of oxygen masks and gloves at high freezing altitudes. Useful hands were furnished them (Graham and Bunnell) by phalangization. The second and fourth metacarpals were removed closing in the clefts by sliding skin and skin grafting, and a rotary angulatory osteotomy was done on the base of the first and fifth metacarpals for better opposition. (Figs 444 and 445)

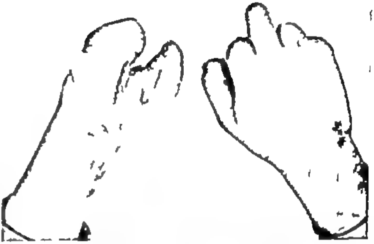
A case of two drumstick hands, caused by falling into hot ashes in infancy, was phalangized by S Haas He separated the metacarpals, forming a thumb and mitten on one hand and a thumb and three fingers on the other Using skin flaps across the clefts, many skin grafts, and a pedicle graft, in 13 operations, enough function was gained for many useful purposes (Fig 451)

Phalangization was done in 1852 by Huguier and later pioneering by Verrall, Arana and Perthes

Rotary Angulatory Osteotomy If, in a hand, the thumb is missing, and also either the long or ring finger, the index or little respectively may be phalangized. The cleft is deepened to the bases of the meta

A B

Fig 444 In an airplane fight at high altitude the oxygen supply was knocked out rendering patient unconscious. On awakening he found his gloves off The hands were so badly frozen that he lost all of the digits of the left hand and most of those of the right. (A *Top left*) On arrival, sequestrectomies were done and the wounds closed. (B *Top, right*) The right hand was given pedicle skin. (C, *Center*, D *Bottom left*, and E, *Bottom right*) Left hand The thumb was elongated by transplanting upon it its metacarpal, part of the second metacarpal, and the remainder of the second ray was excised. In six weeks the thumb cleft was split, its depth was established by swinging a skin flap across it and its sides were skin-grafted. The patient obtained useful hands. (Courtesy of W C. Graham Lt. Col., M C. Valley Forge General Hospital.)



C D

E F

A B

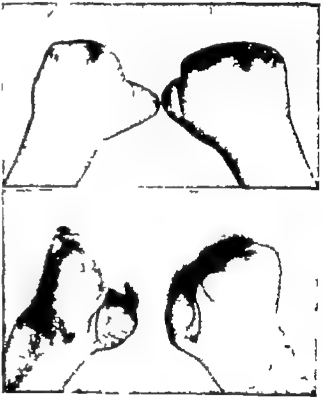
FIG. 445. Case N. R. K., a gunner in World War II. In order to help adjust the mask of his buddy the patient removed his gloves and connected his tube to the other's mask. He went unconscious for two hours at minus 58 C.

(A and B *Top*) Condition of hands after freezing.

(C and D *Center*) All digits were removed at proximal joints leaving him helpless. A year later the following operation was done. Left hand: phalangized thumb and did angulatory rotary osteotomy at base of fifth metacarpal so the thumb could work against it. Right hand: phalangized thumb. Freed and slid mitten of skin over to be used for interdigitations. Excised ring metacarpal for a wide and deep cleft. Did an angulatory rotary osteotomy at the base of the thumb metacarpal so it could work against the other two newly formed digits.

(E and F *Bottom*) Appearance of hands. With these hands he could write, button and unbutton his clothes, pick up a knife, a light book or other objects and use a knife and fork. He picked up objects between thumb and long digits and between the long and little digits against the thenar eminence. He could pick up any small object and hold it firmly. (Operation by author at McCloskey General Hospital.)

C



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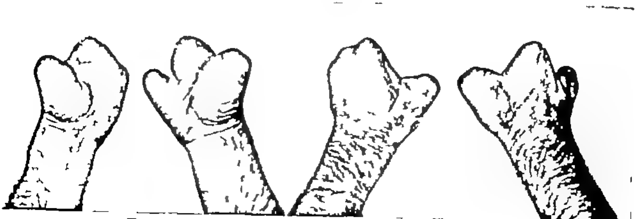


E F

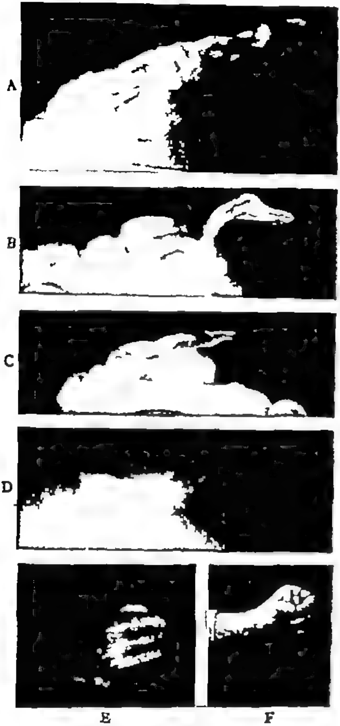


Fig. 446 Case R. K. S. Salvaging a *thumb crippled by osteomyelitis.*

(A) December 25 1932 from an ax cut of the proximal joint osteomyelitis invaded the metacarpal and phalanx. Two months later the sequestra were lifted out and the *Orr treatment started.*

(B and C) Appearance October 30 1933 ten months from accident.

(D) October 31 1933 at operation the middle phalanx was driven into the two adjoining bones.

(E and F) January 23 1934 Thumb 1½ inches long with bones united into one. A strong serviceable thumb was obtained. He returned to work February 20, 1934

carpals, removing the metacarpal of the amputated finger and closing by a plastic maneuver By a rotary angulatory osteotomy, the metacarpal is placed around so *the phalangized finger will* oppose the other

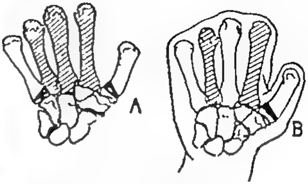


Fig. 447 (A) When all metacarpals except of the thumb and little finger are absent, *one of these or both should be* angulated around by a rotary angulatory wedge osteotomy through the metacarpal base so that the fingers can work against each other

(B) When *all* the digits have been lost, as from frostbite, the second and fourth metacarpals should be removed so as to phalangize widely and deeply between the first and third and the third and fifth. An angulatory rotary wedge osteotomy through the base of the first metacarpal *will place the phalangized thumb where it* will more easily work against the other two phalangized digits.

two fingers at an angle rather than directly opposite. This may be done on two remaining digits, either two fingers or a finger and a thumb, to furnish the pincer action of a lobster claw When only the thumb and little finger remain, the latter can be made to face the thumb better by osteotomy of its metacarpal or by simply removing the *head of the metacarpal of the ring finger* The metacarpal will be more mobile if its transverse metacarpal *ligament is severed.* Nerves, vessels and tendons should be carefully protected to preserve *their functions* in the new position It may be necessary to furnish better control to the digit by grafting tendons between it and some of the spare muscles.

The little finger (Wierzejewski) and the index finger have been rotated by means of

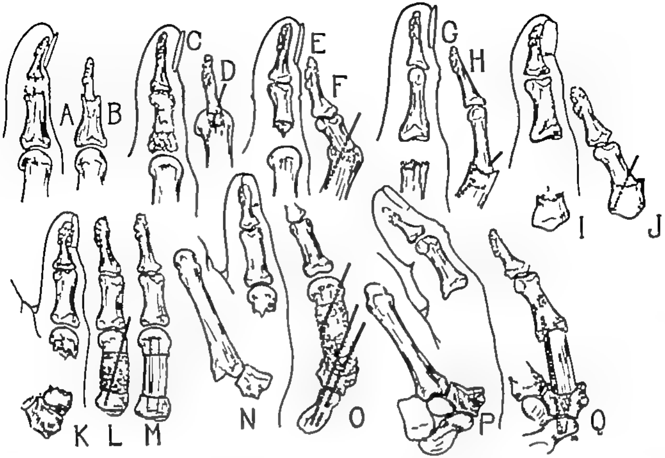


FIG. 448. Stabilizing thumb by arthrodesis and bone grafting A short strong thumb is useful.

(A and B) For loss of distal joint, a distal segment may be fused to proximal.

(C and D) After loss of proximal phalanx, distal phalanx may be fused to metacarpal.

(E and F) Defect in the proximal phalanx is remedied by fusion a pin insuring stability

(G and H) Fusion for loss of head of metacarpal

(I and J) Same for head and shaft of metacarpal.

(K, L and M) Defect of shaft of metacarpal may be filled by iliac or cortical grafts. The shorter immobilization needed for cancellous grafts is that much less time to cause stiffening of the hand.

(N and O) Iliac graft pinned to thumb ray of carpal bones and head of metacarpal to fill large defect of metacarpal.

(P and Q) Defect from loss of metacarpal bridged by cortical graft spiked into proximal phalanx and the thumb ray of carpal bones trapezium and scaphoid.

FIG. 449 Case A. M From one minute's contact with a wire carrying 220 volts of electricity he suffered multiple burns of hand, charred girdling of thumb, necessitating amputation through the base of the proximal phalanx, and loss of some volar skin of the ring finger (A)

When clean the thumb was covered by Thiersch graft and later by tubular pedicle from abdomen a good covering was supplied. The other end of the pedicle was used to replace the cicatrix of the contracture of the ring finger The flexor tendon had been burned from the finger and two months after the skin operation a new tendon was supplied from a graft of the flexor sublimis into this cicatricial bed.

(B C, and D) A serviceable thumb was obtained, and two-thirds flexion of the ring finger

A



B

C



D


E

Fig. 450 Case I. W The hand was crippled from a severe burn from an acetylene blow torch. The thumb was so adherent to the hand by cicatricial contracture that it was useless, as shown in (A) and (B)

A deep cleft was made between the thumb and the hand. A flap of skin from the dorsum was used to cover the thumb and to establish the depth of the cleft, and the denuded area on the hand was covered by a whole thickness of skin graft. At the same time by a tendon graft from the palmaris longus of the other arm, a pulley operation was done, so that the flexor ulnaris muscle would furnish power of opposition to the thumb as the thenar muscles had been destroyed. A useful, movable, and opposable thumb was the result, as shown in (C) (D) and (E)

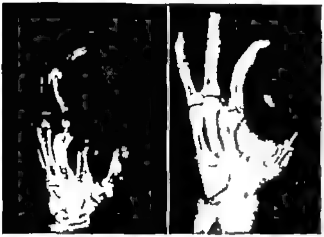
osteotomy through the metacarpal into a position to oppose the thumb or the hand, or to oppose each other (Lausenstein, 1880 Perthes) In a case of loss of index and long fingers the thumb has been made to approximate the little finger by altering the direction of its metacarpal and deepening the cleft (Clapp, 1912, and Lyle)

FIG. 451 Case reported by S L. Haas of boy aged 11 who at the age of 15 months fell with both hands in hot ashes resulting in club contractures. Reconstruction was done by a series of full-thickness and pedicle skin grafts.

(A) Appearance of the hands before operation contracture of right wrist and complete absence of fingers on both hands.

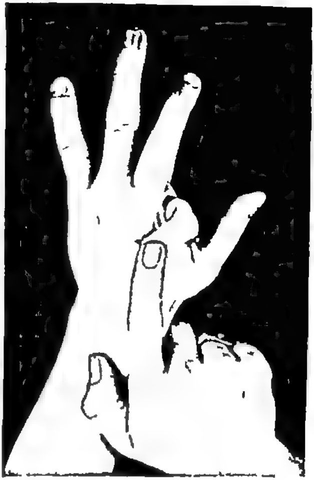
(B) Showing reconstructed palmar surface of left hand and flexion of thumb of right.

(C) Using knife and fork. (Courtesy Haas, S L., in Amer Jour Surg., 36 721–722 1937)



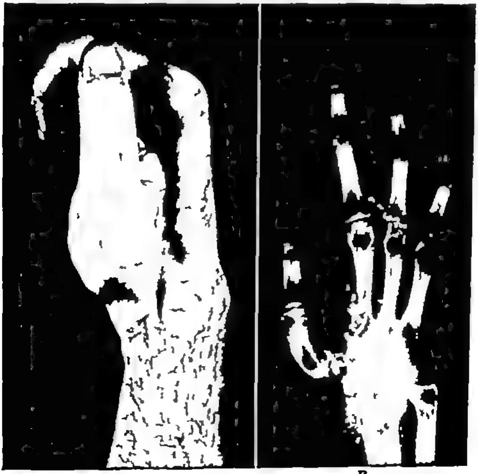
A B

FIG. 452 (A, B and C) Arthroplasty proximal joint long finger Because of loss of proximal joint of thumb arthrodesis was done by pinning The useless index finger was filleted and used to cover dorsum of hand (Courtesy of L. D Howard, Lt. Col. M C., Wakeman General Hospital.)

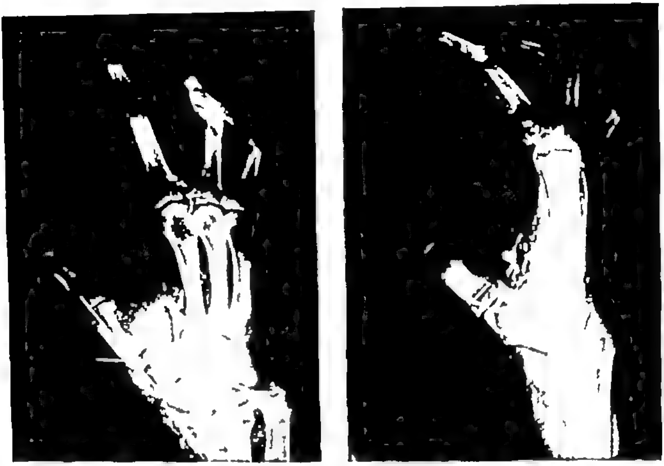


C

FIG. 453 (A and B) Gunshot wound through dorsum of thumb cleft, fusing thumb bones at poor position and causing flexion contracture.

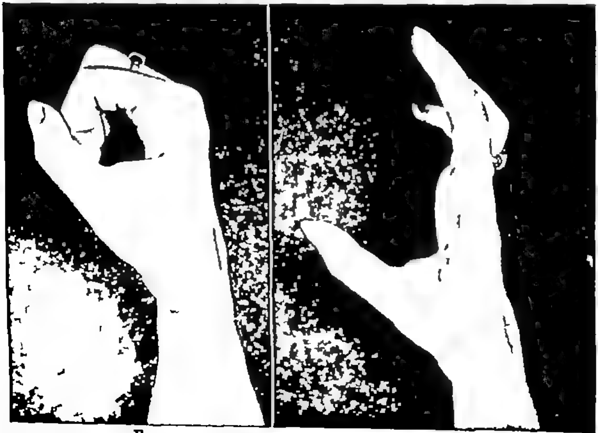


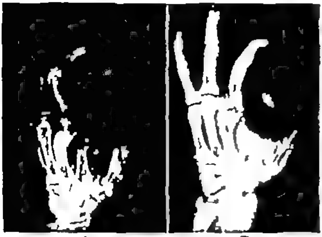
A B



C D

FIG. 453 (C and D *Top*) Excision of scar osteotomy of thumb metacarpal with pinning and application of pedicle in one procedure.
(E and F *Bottom*) Result. (Courtesy of L D Howard Lt. Col., M.C., Wakeman General Hospital.)



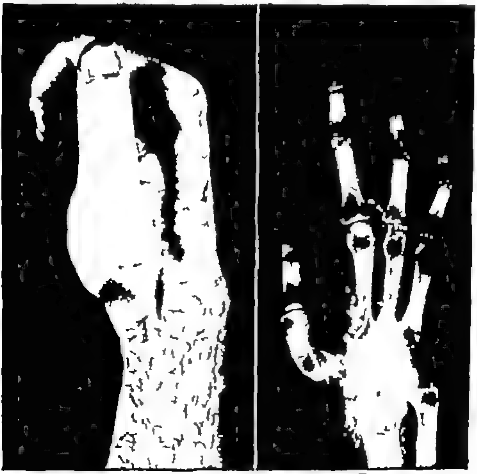


A B

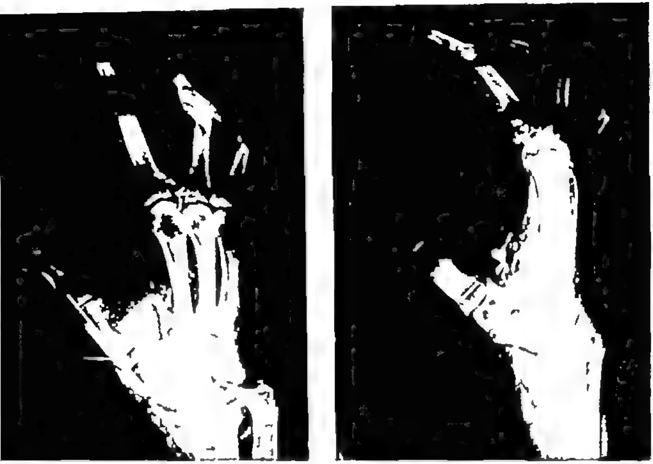
FIG. 452 (A, B and C) Arthroplasty proximal joint long finger Because of loss of proximal joint of thumb arthrodesis was done by pinning. The useless index finger was filleted and used to cover dorsum of hand (Courtesy of L. D Howard, Lt. Col. M.C. Wakeman General Hospital.)

C

FIG. 453 (A and B) Gunshot wound through dorsum of thumb cleft, fusing thumb bones at poor position and causing flexion contracture.

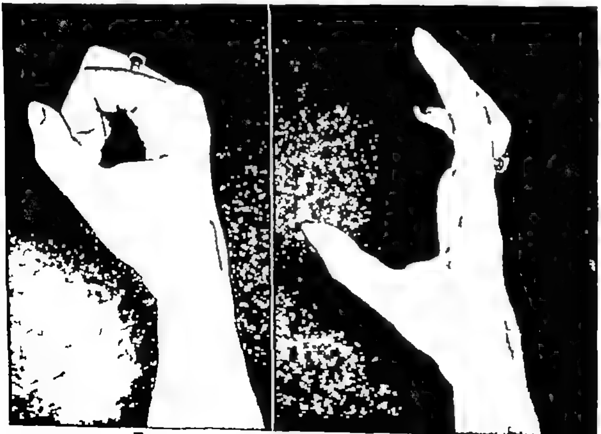


A B



C D

FIG. 453 (C and D *Top*) Excision of scar osteotomy of thumb metacarpal with pinning and application of pedicle in one procedure.
(E and F *Bottom*) Result. (Courtesy of L. D Howard, Lt. Col., M.C., Wakeman General Hospital.)



E F

Whenever from amputation only a few digits are left, these may be given additional strength by *transferring to their tendons in* the forearm the tendons of the amputated digits.

Bone Problems of the Thumb

If a thumb is without bones, a bone may be furnished. Any part of the metacarpal or of the two phalanges may be separated or missing It is only necessary to join what bones are left, usually by bone graft thus making a shorter thumb with fewer joints than normal Such a short and stiff thumb is very useful If the base of the metacarpal is missing, the remainder of it may be ankylosed to the carpus by bone graft. A small triangle of bone graft wedged between the first two metacarpals *will reënforce it against accidental break*

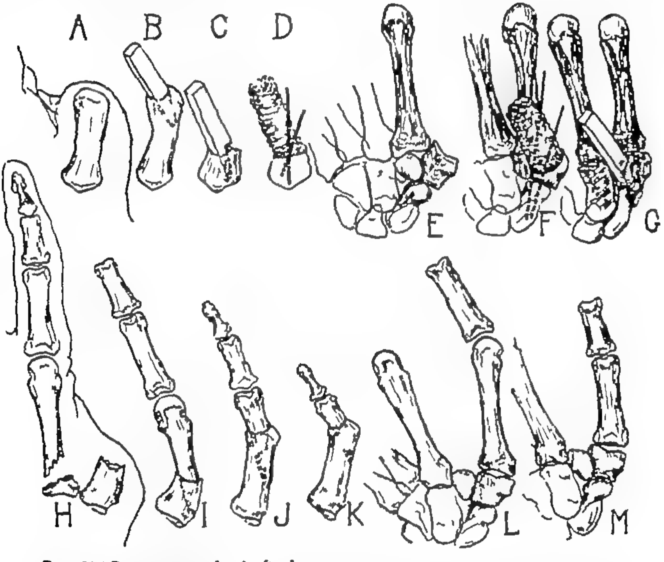


Fig. 454 Reconstructing thumb after loss.

(A B C and D) Building out the metacarpal, or part of it by bone grafts showing two cortical and one cancellous grafts.

(E and F) For complete loss of thumb a post of iliac graft is pinned to the trapezium Thumb posts should be short thick and just inside of the path of movement of the fingers.

(G) Cortical bone thrust through trapezium and scaphoid and should project well *forward to* contact fingers as they close on it. A tubular pedicle is first placed to receive the graft.

(H to M) Pollicization of index finger

(I) Index metacarpal thrust into that of the thumb. *Index shortened by its distal segment*

(J and K) Proximal and middle phalanx of index finger thrust into metacarpal of thumb

(L and M) Metacarpal and proximal phalanx of index finger transferred onto the trapezium. *Index shortened.*

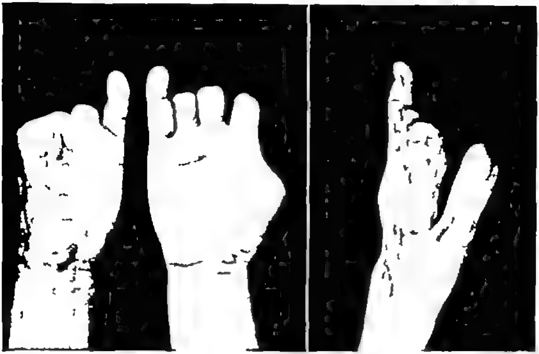
ing If the greater multangular is missing, the metacarpal may be lashed through drill holes by a tendon graft to the scaphoid If both greater multangular and scaphoid are absent, the thumb will be free floating and will be poor of pinch It is best to ankylose it by a bone graft to the second metacarpal For injury to the carpometacarpal joint, arthroplasty has been done. Only if it is quite stable, like a ball and socket joint, or has good cartilages and is lashed in place by tendon, will there be painless strength of pinch without backward dislocation In general arthrodesis of this joint is preferable.

Transplanting Index Finger to Position of Thumb (Pollicization with Index)

The index or long fingers together with a part or the whole of the metacarpal have been transplanted to the stump of the metacarpal of the thumb or to the trapezium, but without conservation of all nerves tendons, and muscles (Perthes, Verrall, two cases in 1919, no joining of tendons or nerves, Dunlop, in 1923, using pedicle skin from abdomen for the cleft, Huguier, Iselin)

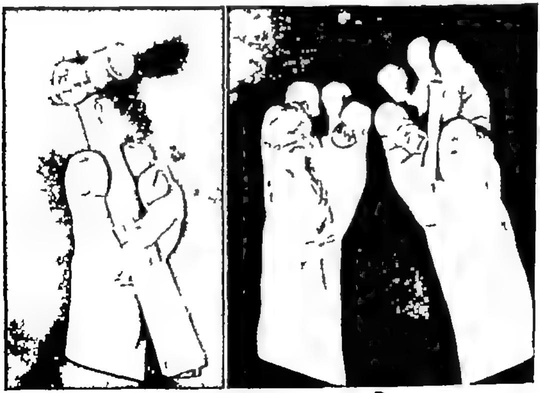
A full length of finger is too long and too tapering to make a good thumb, and if not successful the sacrifice of a good finger will be lamented by the patient. If the operator knows from experience that he will succeed, it is justifiable to transplant a normal index finger to act as a thumb, but only so if nerve and blood supply and tendons are brought over intact and the tendons and muscles of the thumb are added. The index finger is amputated at its distal joint. Often, however, part of the index finger has already been amputated with the thumb, thus making its remainder available. A personal case of transference of the index metacarpal and phalangeal stump to the trapezium together with all nerves, vessels, establishment of connections of all tendons and muscles, and phalangization, is reported in detail below because it was the first thumb reconstructed that was furnished both movement and normal sensation If the index finger is off through the middle or distal joint, or between them, it may as a whole be transferred over to act as a thumb In absence of the thumb metacarpal the index metacarpal is dislocated to the greater multangulum, but, if present, the distal part

Fig. 455 (A, B and C, *Top to bottom*) Pollicization of index finger preserving nerves Cleft was made by tube pedicle. Tendons were joined but joints were stiff (Ernst Dehne Lt. Col., M.C., Oliver General Hospital.)



A B

FIG. 456 Reconstruction of thumb after loss of digits.
(A) Preoperative.
(B) (*Left*) Pollicization and phalangization of index ray. Second metacarpal was lashed by tendon to greater multangular. The long tendons of the thumb were transferred to those of the index finger. Sensory nerves were preserved and carried with the finger.
(*Right*) Thumb has been phalangized, and an angulatory rotary osteotomy was done on the base of the fifth metacarpal.
(C and D) There was good function. (Courtesy of William H. Frackelton, Lt. Col. M.C., Beaumont General Hospital.)



C D

A

Fig. 457 (A and B *Left*) Thumb was amputated by a shell fragment and the second metacarpal fractured The index finger was transferred to act as a thumb

(C *Below*) At the first stage the proximal phalanx of the index was grafted into the metacarpal of the thumb

B

C

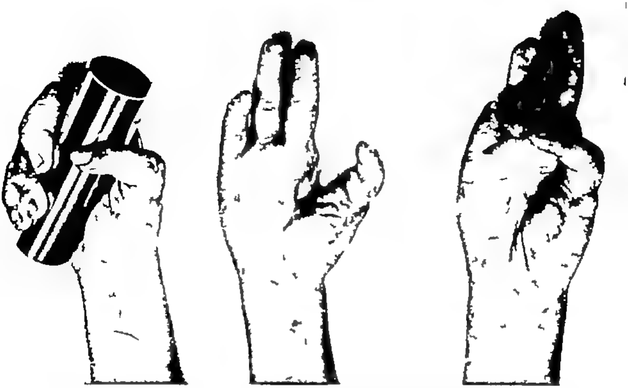


FIG. 457 (D E and F) At the second stage a cleft was made guarding well the nerves and tendons of the index finger so that it will have motion and sensation. The patient obtained a thumb almost as useful as normal. He could move it into position to grasp large or small objects (Courtesy of W C. Graham, Lt. Col., M.C. Valley Forge General Hospital.)

of the metacarpal of the index, or its proximal phalanx, may be fused by dovetailing to the remains of the thumb metacarpal. In World War II, in our Army hospitals, the operation was done about 15 times A good routine was to first do the work on the soft parts, completing any deficiency of skin by a tube pedicle, and then to attach the bones and tendons

Repair of Thumb After Bony Injury

Amputation Through Metacarpophalangeal Joint. *A thumb will be long enough to be serviceable, but should be made relatively ¾ inch longer by phalangization.* It may be built out longer, though without this it has the advantage of having natural sensation.

Loss of Shaft of Metacarpal By excising all cicatrix length can be gained. The gap in the shaft should be filled by a bone graft. (See Bone Carpentry)

Loss of Head and Shaft of Metacarpal The linear bone graft is impaled into the metacarpal base and into the proximal phalanx.

Loss of Shaft and Base of Metacarpal. The linear bone graft impales the head of the metacarpal and the two carpal bones, trapezium and scaphoid, or an iliac graft may be pinned in place.

Loss of Whole Metacarpal A linear bone graft, such as a rib or piece of ulna, impales the proximal phalanx and the trapezium and scaphoid. A defect in the phalanges is similarly treated by bone graft or a proximal phalanx may be impaled on the metacarpal.

Loss of Carpal Support of Metacarpal. The thumb will be free floating A mechanical support must be provided. If the trapezium is present, the metacarpal is joined to it using a bone graft. If it is removed and there are joint surfaces on metacarpal and scaphoid, these two may be

lashed together by a tendon through drill holes If both trapezium and scaphoid are absent, the metacarpal of the thumb may be joined to that of the index finger either di rectly or by a bone graft

A reconstructed thumb should always be placed for use in a position directly in the pathway of the fingers and enough to the radial side to allow the fingers to deviate and pass it

Building New Thumb or Elongating It by Tubular Pedicle and Bone Graft

If a thumb is off at the metacarpophalangeal joint, its function may be improved by

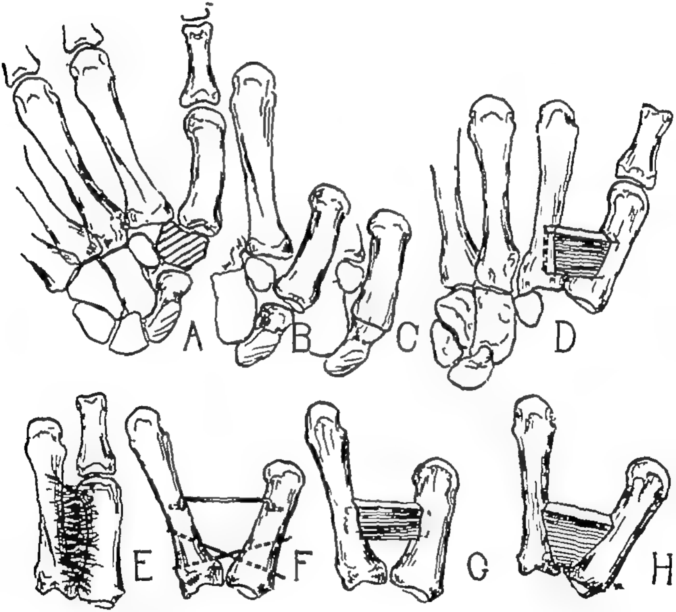


Fig 458 (A to D) When the carpals that support the thumb are absent the thumb meta carpal needs stability

(A, B and C) When the trapezium is absent, the thumb metacarpal may be made to articulate with the scaphoid or into an improvised socket in the carpus. Arthrodesis to the scaphoid gives stability without too much loss of motion.

(E to H) When cicatrix between the first two metacarpals draws the thumb close to the hand, excision of the cicatrix allows spreading. A *pedicle* skin graft may be necessary

(F) Contracture will reproduce unless metacarpals are held apart for a few months as indi cated. The lower is the better method.

(G and H) If cicatrix is excessive a bone block or bridge graft in the position of moderate opposition will insure permanent spreading.

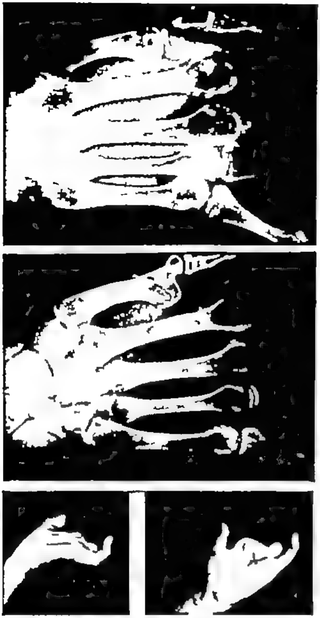


FIG. 459 Case L. W Reconstruction of thumb.

(*Top*) From loss of a large portion of the proximal phalanx from automobile accident the thumb was flail and useless.

(*Middle*) The fragment of the proximal phalanx was thrust into the metacarpal. A new extensor and flexor tendon and opposition by a pulley operation were furnished.

(*Bottom*) Showing motions of the thumb which is now useful.

building it moderately longer by tube pedicle and a bone graft placed at an angle ulnarward Left as it is but made relatively longer by phalangization a thumb amputated at the metacarpophalangeal joint will be useful and has the advantage of having natural sensation. If the metacarpal is any shorter than its full length it is well worth while to build the thumb longer The presence of even a stub of metacarpal is of great advantage as its motion will be imparted to the thumb Even those thumbs that stand out from the carpus rigidly as a post prove to be a valuable addition to the hand. They will be used while a prosthesis, because of its nonsensitivity, will be discarded

The tubular pedicle of skin is taken from the abdomen or acromiopectoral region and the bone from ulna, tibia, rib, or ilium. The bone has been transplanted previously under the abdominal skin so as to be carried over with the pedicle. Albee carried a piece of clavicle with the pedicle. There is no advantage of carrying the bone with the pedicle. The difficulty is merely increased in attaching the bone to the hand and the piece is apt to be detached in transit It is preferable first to attach the pedicle to the hand or base of thumb with the seam of the pedicle dorsal, and three weeks later to detach it from the trunk leaving a liberal blind end. Sometimes the blind end of a pedicle becomes cyanotic, so it is better to have a little reserve length in case of necessity After the new soft thumb has vitality, it is reopened along the scar and the spike of bone is driven into a hole drilled in the metacarpal if present, or if not, the carpus —preferably impaling the trapezium and scaphoid as these two carpals give some thumb motion when tendons are attached to the thumb Care should be taken to drive the spike in the correct position of opposition, drilling the hole for it at a forward angle when necessary If ilium or rib is used it is pinned in place. Operations by the above methods have been reported by Nicoladoni 1897, Schepelmann, Ritter, Payne, Albee Pierce, Dial and others. A great number were done in World War II L D Howard succeeded in placing a tube pedicle and bone graft in one stage.

Such a thumb though at first anesthetic will gradually acquire a certain degree of sensation to light touch and pinprick which

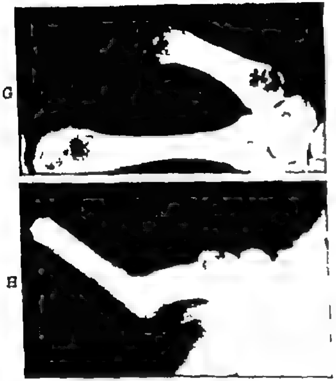


Fig. 460 Case A. L. R aged 15 Loss of thumb

At age of seven right thumb was amputated in the cogs of a feed grinder through the base of the metacarpal

(A) Preoperative condition of stump amputated through middle of metacarpal terminated by cicatrix and having good movement

Operation in stages. Cicatrix was excised establishing a deep cleft and an abdominal tubular pedicle was sutured to the end later severing the pedicle leaving a blind end.

Three months later a bone graft from tibia was placed in pedicle pointed and driven into the split metacarpal. New thumb needed a protective encasement to prevent trauma to insensitive end until sensation returned, which was in two years

(B C, D E and F) A very useful thumb was obtained with full movement of the metacarpal

(G and H) X ray films before and after operations.

reaches to the end after about a year, but it never acquires stereognosis as a thumb should because such special touch corpuscles are not in abdominal skin Until sensation to pin prick returns, a synthetic thumb should be carefully protected against burns or injuries by wearing a thumb cap If a trophic ulcer once starts it will continue because a newly grafted bone is unable to slough off a surface sequestrum. Should the bone graft be exposed in a trophic ulcer it is best at once to remove it, and later when all is clean to replace it with another graft These thumbs, if they are in good position of opposition, become very useful If the thumb is made parallel to the hand or where it cannot be used the bone will atrophy from disuse. Conservation should guide us in treating injured thumbs building them out if the end is poor rather than amputating A tip of thumb can be added by pedicle in one stage A thumb in the right position is useful even though it is short and several of its joints are fused A long post like, immobile thumb is in the way in entering pockets working in tight places and it might break. A post thumb is better short and thick and in a position where the

fingers work against it easily It should resemble the pad in a palm of a rodent, such as a squirrel, against which the digits grasp

Digital Transplantation

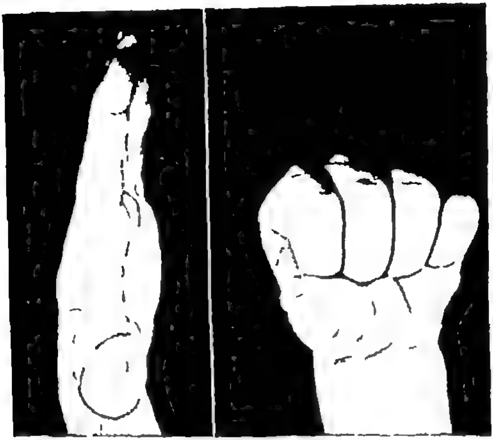
In many cases a digit has been actually transplanted from the same or the other hand or from the foot to act as a new thumb This can readily be done by the pedicle method, though in many instances necrosis has occurred. The limber joints of children have better tolerance than those of adults to the strained position when holding the hand next to the opposite foot. If a digit is transferred from one hand to the

A

Fig. 461 A new thumb was made by tube pedicle and rib It had slight motion. The patient could pinch between it and the index finger Six months later patient stated that he liked the thumb and that it helped him use his hand. (A) The thumb contained its metacarpal stub but was useless as there was no thumb cleft. (B) Bone graft for metacarpal. (C) Much function gained by phalangization. Note A post thumb that is short, thick and in the zone of the fingers is desirable. (Courtesy of William H. Frackelton, Lt. Col. M.C. Beaumont General Hospital.)

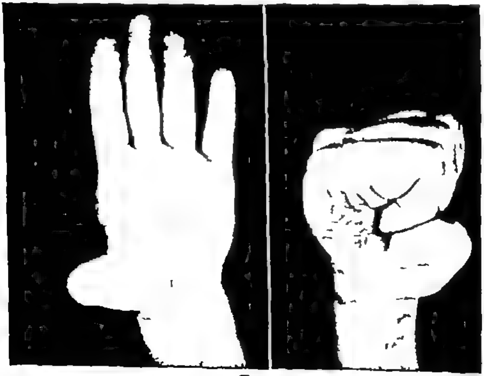
B

C



D

FIG. 462 Same case as Figure 461 (D and E) Much function gained by phalangization. (Courtesy of L. D Howard, Lt. Col., M C., Wakeman General Hospital.)



E

fingers work against it easily It should resemble the pad in a palm of a rodent, such as a squirrel, against which the digits grasp

Digital Transplantation

In many cases a digit has been actually transplanted from the same or the other hand or from the foot to act as a new thumb This can readily be done by the pedicle method, though in many instances necrosis has occurred. The limber joints of children have better tolerance than those of adults to the strained position when holding the hand next to the opposite foot. If a digit is transferred from one hand to the

A

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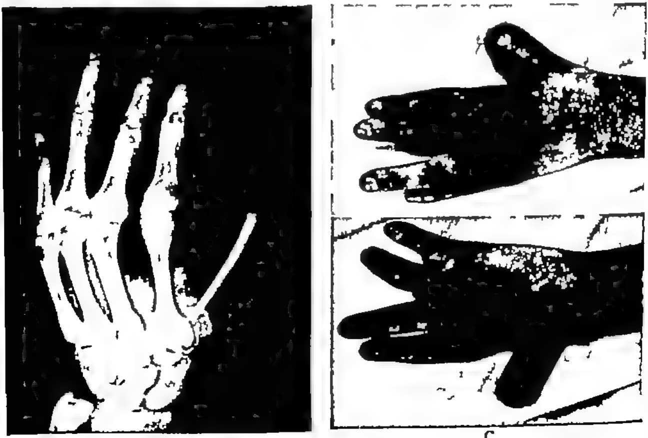
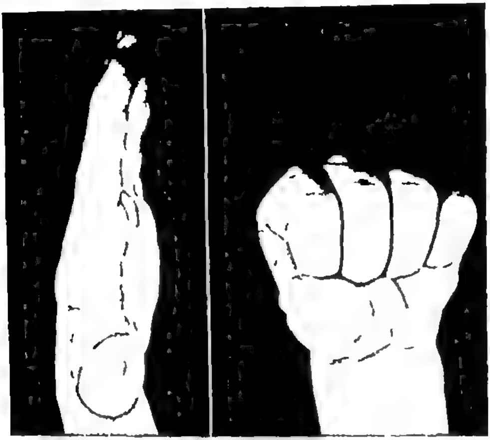
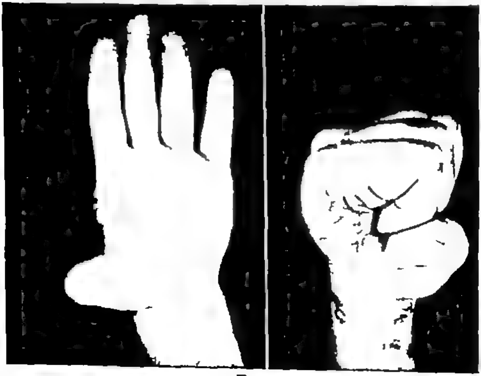


B C



D

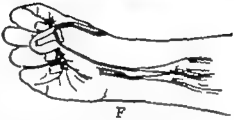
FIG. 462 Same case as Figure 461 (D and E) Much function gained by phalangization (Courtesy of L. D Howard Lt. Col., M.C., Wakeman General Hospital.)



E

A B C D E

FIG. 463 Case A. S., aged 13 Reconstruction of a thumb. The thumb was denuded to its base by catching be tween a rope and a pommel. Skin, tendons, and bones except part of proximal phalanx were lost. Arriving late, the de nuded stump was cleansed by compresses and later covered by thin skin graft. A tubular pedicle prepared on the abdomen was later used to replace the skin graft in covering the thumb



F

(F) Later the tendon of the palmaris longus as a graft was passed through a drillhole in the prox imal phalanx. One end was attached to the tendon of the extensor pollicis longus. The flexor pollicis longus had been evulsed so the other end was attached to the flexor profundus tendon of the index finger transferring the distal portion of the latter to that of the long finger

(A, B C D and E) A good serviceable thumb was obtained with sensation, motion, and strength.

other during the time the hands are at tached the patient is dependent on others for his bodily needs. This method was condemned by Moreston at the International Surgical Congress, New York, 1914 *The transplanted digit undergoes atrophy* as in a paralytic finger or one with a girdling scar, all of its tissues suffering Sensation is very poor No one until recently has reported reconnecting the nerves. Trophic sores and deep, progressing ulceration have occurred. In most cases the new digit is hooked atrophic, stiff and without motion. Gueullette in 1930 reported that in 20 collected cases, five of the second toe, 12 of the great toe and three of the fingers transplanted for a thumb, only seven had active movement and only three were perfect. Five necrosed or ulcerated.

To take a normal finger, usually the ring or long, from the other hand is mutilating, and in addition it will probably not be suc cessful. The second toe is too narrow and weak and the great toe is too gross. Nicoladoni pioneered this in 1898 and retained tendon function Joyce in 1917 in two cases used the ring finger Esser transplanted four metatarsals and toes to a hand and 20 years later the patient could hold objects and draw There was some motion, but sensation was poor and without stereognosis Other transplantations of digits were reported by von Eiselsberg, Krause, Klimm, Kleinschmidt, Blair, Neuhof and Young

Of late some digits were transplanted more successfully as attention has been given to *joining the nerves* H Hoyle Campbell used a toe for a thumb, and, in two cases which I saw, made a thumb from the ring finger of the opposite hand. First the two ring fingers were joined by fishtailing their ends. Then the finger was transferred to be a thumb The nerves were sutured. There was some motion and strength. Sensations returned but not stereognosis. The trophic condition was good and the patients liked them

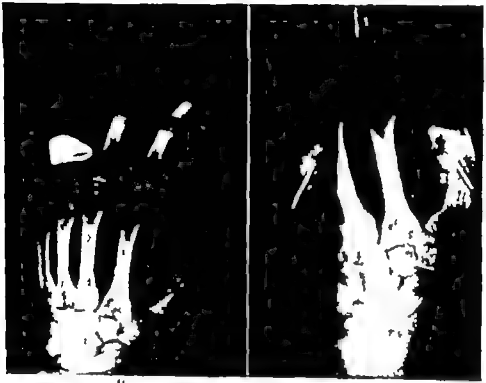
It seems preferable, whenever possible, to construct a thumb by pollicizing the index finger with all its tendons and natural unsevered nerve supply

COMBINATION OF METHODS

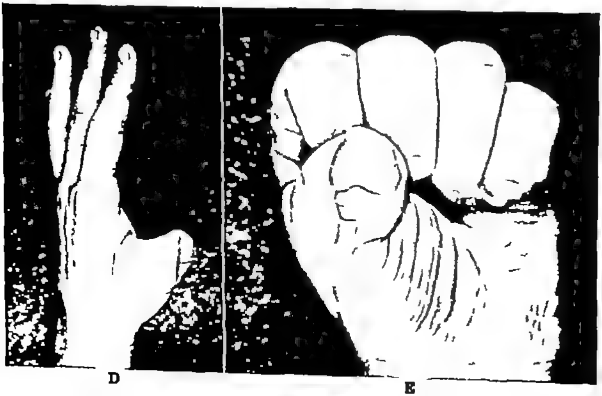
Each case is individually dependent on the degree of crippling and the parts that

Fig. 464 Extension of thumb by short bone graft and pedicle skin
(A and B) Preoperative.
(C) Bone graft pinned into bones of thumb
(D and E) Good function (Courtesy of L. D Howard Lt. Col., M C., Wakeman General Hospital.)

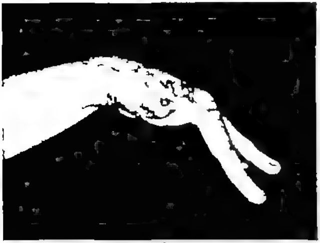
A



B C



D E



A

FIG. 465 Reconstruction of thumb (A *Top* and B *Bottom*) Preoperative.

B

are available and also on the type of work done and the cosmetic needs, the appropriate method being chosen accordingly Various procedures may be combined such as phalangization, osteotomy, transplanting or elongating by pedicle and bone graft. Wherever possible, sensation and trophic influence should be furnished by restoring nerve supply by suture Motion and muscle balance should be restored by attaching to the new thumb all available tendons and muscles, or by using free tendon grafts to connect available muscles to the new member to give it opposition, flexion, and extension (Figs 463, 468 and 470)

Physiologic Reconstruction of Thumb After Total Loss*

Preservation of Motion and Sensation. In the function of a hand, motion and sensation are of equal importance and this is especially true of a thumb The hand which is our sense organ of stereognosis is guided in its work by muscle, joint, pain and temperature sense, and the sense of touch. We are all familiar with how awkward and useless our hand becomes when numbed with cold. When the nerves to the digits are severed the handicap to the workman is great. He is awkward and fumbles and drops objects His hands are like the legs of a man with locomotor ataxia, and cannot function without visual guidance. Therefore the thumb to be reconstructed should, if possible, have normal sensation

If the two volar nerves to a finger are severed, that finger becomes practically useless An annular scar still further wrecks a digit by also curtailing its lymph and blood supply Trophic atrophy and loss of function result. If, then, a thumb is reconstructed by transplanting to the hand a digit from the other hand or the foot, or from a tubular pedicle skin graft taken from the abdomen and stiffened by a

* Reprinted in part from Surg., Gynec., and Obstet., 52 245–248, Feb 1931

C

D

E

F

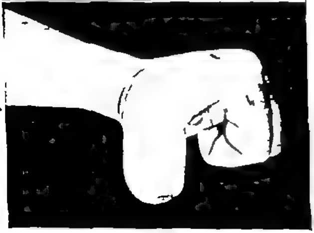


Fig. 465 (C, *Left top* and D *Right top*) Second metacarpal pinned to elongate first metacarpal.

(E, *Left center*) At the same time a tube pedicle was applied.

(F *Left bottom*) Now that the thumb is constructed it must be osteotomized into the zone of finger movement. (Courtesy of L. D Howard, Lt Col., M C. Wakeman General Hospital.)

bone graft, there will follow trophic atrophy equivalent to that seen in a digit that has an annular scar at its base

In some cases the reconstructed thumb will acquire a slight degree of sensation, but it will be greatly limited and not to the degree of stereognosis. A finger with volar

A

B

FIG. 466. Transfer of digit to thumb by means of a tube pedicle.
(A and B) Preoperative. Absence of thumb and index poor long finger
(C and D *Bottom*) Pedicle attached to long finger to transfer it to thumb

C D

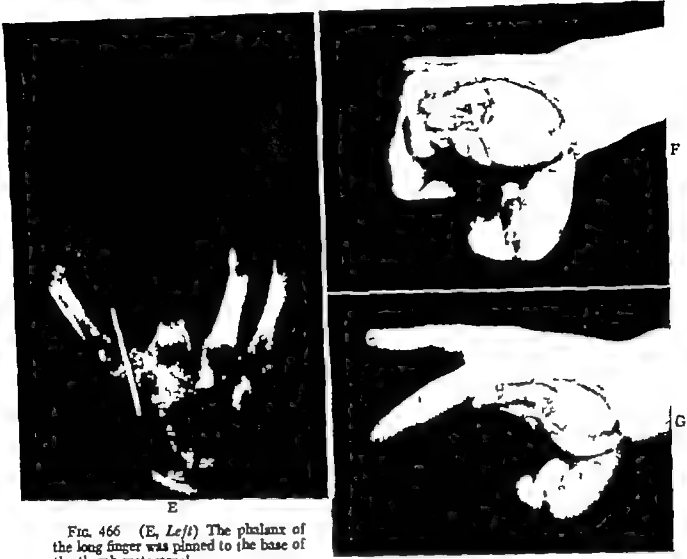


FIG. 466 (E, *Left*) The phalanx of the long finger was pinned to the base of the thumb metacarpel.
(F and G, *Right*) Final result. Thumb may be moved into zone of fingers. (Courtesy of L. D Howard, Lt. Col., M.C., Wakeman General Hospital.)

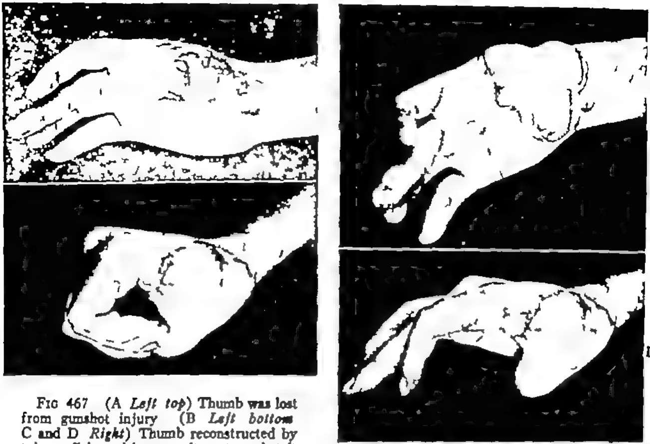
nerves cut is permanently anesthetic. Recently, I saw one that was still anesthetic from severance of a volar digital nerve in the palm 20 years previously

Strangely enough, a little better sensation will be acquired in a whole finger grafted on, or one made from a tubular skin pedicle, than will follow in a finger after the two volar nerves have been severed. This is apparently because more free nerve endings start to grow down the new digit. On the other hand, when the two main nerves alone are severed, these become sealed by neuromata, and the unsevered minor nerves already have their normal terminations, so that no free nerve ends are available to grow down the finger

Unless we graft the natural nerve supply with a digit or suture the two volar nerves of the new digit to those at the base of the lost digit, the proper degree of sensation and trophic influence will not be acquired. Also, if our reconstructed digit is made from abdominal skin it will lack the specialized touch corpuscles present in a finger so it can never acquire stereognosis to a better degree than that poor quality present in abdominal skin To test this, press a pen knife against the abdominal wall and try to identify it. A prosthesis as a substitute for a thumb is usually discarded, as it has no motion and no sensation.

Other requisites to be sought for in reconstructing a thumb are strength, durability, movability, and the functioning position of opposition The latter depends in the case of a movable thumb on the proper balance of the muscles, and this is best ob-

A



B

C

D

FIG 467 (A *Left top*) Thumb was lost from gunshot injury (B *Left bottom* C and D *Right*) Thumb reconstructed by tube pedicle and bone graft post so that it is short, thick and in the zone of finger movement, much like the pad in the hand of a rodent. (Courtesy of L D Howard, Lt. Col., M C., Wakeman General Hospital.)

tained by attaching the normal muscles and tendons to the new thumb and in their normal relation.

In the reconstruction of the thumb to be described, the normal nerve and vascular supply were preserved and all of the muscles and tendons of the old thumb were attached in their former arrangement to the new thumb These principles, which have not been carried out in the previously reported cases of thumb reconstruction in our literature are offered as sufficiently important to be adopted whenever possible

Case Report. Case H W W., aged 40 years. A year previously a circular saw amputated the thumb through its carpometacarpal joint and the index finger through its proximal phalanx. Patient had not been able to work at his trade of carpentry since the accident.

DISCUSSION All structures necessary for making a new thumb were present, and fortunately were then of no benefit to him as they were nonfunctioning They consisted of the following there was a long enough portion of the second ray for good length of thumb composed of the second metacarpal and half the proximal phalanx of the index finger This had attached to it two flexor and two extensor tendons which could act on the metacarpophalangeal joint and also on the new joint to be constructed between the base of the second metacarpal and the trapezium. In addition, he had normal blood, lymph, and nerve supply for the new thumb which could be preserved. He also had the normal specialized sense organs of the skin of the hand which convey impressions of stereognosis in a refined way For attachment to the transplanted member were all five muscles of the thenar eminence with their normal nerve supply, the long flexor tendon of the thumb, and the three extensor tendons, also the four tendons of the index finger Thus, eight ten-

dons and five thenar muscles, which were already balanced, were more than ample for stability and strength and most of them were already educated for use in thumb function

Fig. 468 Showing condition of hand before reconstruction The thumb has been amputated through its carpometacarpal joint and also the index finger as frequently happens, through its proximal phalanx. The hand is unfit for work. (Courtesy Surg Gynec., and Obstet., 52 245 1931)

Operation (April 10, 1929) Skin flaps were so constructed that a flap from the dorsum of the hand was utilized to close in the raw surface of the newly constructed thumb Another flap from the palm was made to cross the bottom of the cleft between the new thumb and the hand, so as to maintain the depth of the cleft.

The old scars in the hand were excised The two tender neuromata of the nerves to the amputated thumb and the two to the amputated index finger were dissected out and cut off after the main trunks had been ligated and injected with alcohol to prevent reformation of neuromata.

The remains of the index ray which consisted of half the proximal phalanx, the two flexor and extensor tendons, nerves, and

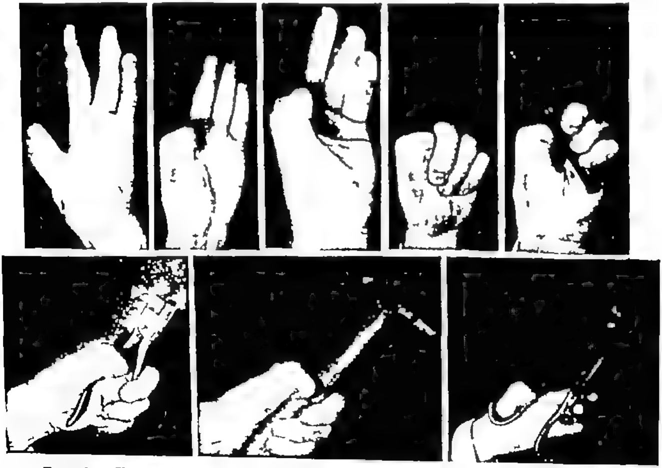


Fig. 469 Showing results of physiologic reconstruction of thumb from remains of index finger and second metacarpal. Normal nerve and blood supply have been preserved and all of the tendons and muscles of the index finger and thumb have been attached to the new digit. The thumb has movement, strength, and normal sensation, including stereognosis. (Courtesy Surg., Gynec., and Obstet., 52 246 1931)

blood vessels and the metacarpal were transplanted en masse to the position of a thumb, ample blood supply being left in the posterior and anterior pedicles. The proximal end of the second metacarpal was disarticulated from the carpus and transplanted to the trapezium to form the new joint. With it was taken the lower three inches of the tendon of the extensor carpi radialis longus, and this was passed through drill holes in the trapezium and metacarpal so as to encircle the joint and to stabilize it against dislocating The upper or muscle end of this same tendon was fastened in the forearm to the extensor carpi radialis brevis tendon for added strength of extension of the hand. The surface of the second metacarpal is well adapted to rest on the saddle of the trapezium and in the correct rotation for opposition.

The original three extensor tendons of the thumb were united to their respective sides at the base of the transplanted metacarpal by passing the sutures through a drill hole in this bone Good osteoperiosteal and tendon contact was established. The original flexor tendon of the thumb was dissected out and united to the two flexor tendons of the index finger so as to give added strength of flexion to the new thumb

In the transplantation of the index finger the volar digital nerve to the second interdigital cleft was slit longitudinally up to the base of the palm, so that sensation would be preserved both on the radial side of the long finger and on the ulnar side of the in

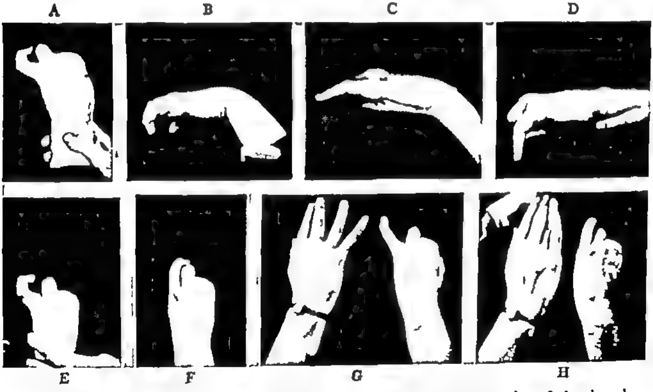


FIG. 470 Case L. W., aged 26 (Same case as Fig. 459) Reconstruction of thumb and interosseus function. From an automobile accident eight months previously

Operation for loss of interosseus muscle of little finger

(A and B) Here is seen loss of action of interosseus muscle. Little finger adducts and cannot extend in its distal two joints.

To correct these the palmaris longus was used prolonging it with a free graft from an extensor tendon of an amputated finger to pass down the lumbrical canal and unite to the tendon of the radial interosseus muscle a lateral band in the little finger by removable stainless-steel wire This replaced strongly the function of the lost interosseus muscle.

(C and D) Ability to extend the distal two joints when proximal joint is straight or flexed.

(E, F G and H) Good power to adduct and abduct the little finger

dex finger The fork of the volar artery to this cleft was cut and ligated on the long finger side to give richer blood supply to the new thumb The posterior interosseus muscles in the first and second cleft were preserved with their same attachments and the anterior interosseus muscle in the second cleft was also preserved with its attachment All the small thenar muscles were dissected out and attached to the metacarpal of the new thumb

The new thumb was completely enclosed in skin by the flaps from the dorsum and palm of the hand Eventually there was a denuded area about 1 inch wide and 5½ inches long running obliquely across the dorsum of the hand through the newly constructed cleft and around across the palm This was filled in with a whole-thickness skin graft taken from the abdomen Rubber sponge pressure was used in the dressing

Result The action of the wrist and remaining three fingers is normal The newly constructed thumb has movement. It can touch the full length of the long finger and the base and tip of the ring finger It can spread 1½ inches from the base of the long finger making possible an open grasp It has the ability to oppose the other fingers, in that patient can place the thumb in a position forward from the hand in grasping. It adducts to the center line of the long finger The thumb has two movable and stable joints, a metacarpotrapezial and a distal joint. The latter, which formerly was the proximal joint of the index finger, has 25° of motion and is in a position of function The thumb is exceedingly strong in all its movements, as it has the combined strength of the index finger and thumb, thus having eight functioning tendons instead of the normal four It is also controlled in its movements by the thenar muscles which are attached to its metacarpal and are functioning

A feature of great importance is that the new thumb has natural sensation and vascularity, as the nerves and blood vessels have been transplanted with it With the faculty of stereognosis it is most valuable to the patient in his work. The hand is covered with good skin throughout, is free from deforming cicatrices, and is painless For the last 19 years the patient has been able to pursue his trade of carpentry

The above was done in one operation Since this case a number of thumbs have been reconstructed from the index finger, preserving motion and sensation A practical procedure is first to deepen and widen the cleft between the index and the long finger metacarpals and to apply in the cleft a pedicle graft from the abdomen

A simpler and still more successful method of transferring any digit from the same hand to act as a new thumb is to do so by using a blood vessel, a nerve and a tendon pedicle without any connecting skin. By careful dissection the nerve is slit down at the cleft from that to the adjoining digit, vessels are carefully protected, ligating and severing those branches to adjoining digits, and the new digit is contacted firmly and positioned by attaching its bone to whatever is left of the bones of the thumb The extensor and flexor tendons transferred with the digit are shortened if necessary, and the tendons and the intrinsic muscles of the original thumb are transferred to act on the new member (see p 159) Thus the new thumb will have both sensation and motion

In the second operation the pedicle may be disconnected from the abdomen, and the *metacarpal* of the index finger may be placed on the stump of the metacarpal of the thumb or lashed to the greater multangular bone

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11

The Arm in Its Relation to the Hand

HAND DEPENDENT ON ARM

With our attention narrowly focused on the hand, we must be mindful that its function is dependent on that of the arm Thus, whatever affects the arm nerves anywhere in their course from the spine also affects the function of the hand. Hand motions are for naught without arm movements to place the hand, and limb muscles controlling the joints to stabilize the extremity as a whole. How often, too, is diagnosis misled by the symptom's apparently being of the hand when the real pathology is higher—at, say, the spinal foramina, the scalenus anticus muscle, or the brachial plexus.

It is not my purpose to cover the whole surgery of the arm, but merely to deal sketchily with those conditions of the nerves and the movements of the arm affecting the hand which the patient may present when coming for reconstruction Commencing at the neck and progressing anatomically down the arm the general principles of the ailments will be outlined, referring the reader to the bibliography for the details.

PRESSURE ON NERVES IN NECK

At Spine

There have been many reports of symptoms in the hand caused by pressure on the nerves emerging from the cervical spine in cases of vertebral luxation, fracture of body or articular process, disc lesions, and hypertrophic arthritis with spurs encroaching into the spinal foramina. A frequent cause is a displaced cervical disc as described by Semmes Discs displace at the vulnerable level of the cervical spine, namely, 5th and 6th vertebrae, and press on the nerve just below The 5th disc presses on the 6th nerve causing paresthesia down the radial aspect of the arm and hand, and the 6th affects the 7th nerve projecting down the middle aspect affecting the index finger The biceps reflex is from C 5 and C 6, triceps C 6 and C 7 and wrist C 7 and C 8 The usual history is of a few cricks in the neck Then greater pain with projections down the arm, down the back and over the precordium suggesting brachial neuritis, coronary trouble or angina. Pain paresthesia, numbness, loss of reflex and x ray appearance of the spine lead to the diagnosis Bending the neck away from the lesion helps the pain and towards it increases the symptoms, as does pressing on the head or jarring the site in the spine. At operation under local anesthesia, a tug on the ligamentum flavum produces the pain verifying the level.

Haufleg and Oppenheimer have stressed the hypertrophic arthritis theory, but the osteophytes could have resulted from the spinal injury from which a disc protruded.

The foramina are large vertically but narrow horizontally Flexion of the neck opens them

SCALENUS ANTICUS SYNDROME

Mechanism. The brachial plexus and subclavian arteries may be compressed by the scalenus anticus muscle as it passes over them to insert on the first rib The cause may be prominence of the bone beneath (cervical rib or overlarged seventh transverse process), or may be from spasm from disc pressure and consequent hypertrophy of the scalenus anticus muscle In some the excessive drooping of the shoulders and ribs, making a relatively long neck, brings about the compression, and this explains the greater frequency in women than men and the greater occurrence in middle life. Cervical ribs were considered as the primary cause until Adson and Coffey in 1927 showed that over half of these ribs did not cause symptoms and that the scalenus anticus is the greater offender Cervical ribs are old in phylogeny, being present to as far back as the head in fishes and many reptiles. In many cases there is no cervical rib or large transverse process, the scalenus anticus muscle compressing the structures against the first rib

Symptoms. The lower part of the brachial plexus (C 8 and T 1) fitting into the V between muscle and rib is squeezed causing pain—both steady and increased by position and occupation—mostly in the areas supplied by the internal cutaneous ulnar, and median nerves

If the pain radiates down the back and over the precordium and the nerve roots affected are 6th or 7th one should suspect disc. The hand wrist and forearm may feel numb and tingle, and involvement of motor function is apparent in weakness atrophy of the intrinsic muscles of the hand —usually of the ulnar but sometimes of the median—with consequent atrophy and the deformity of clawhand with thumb at side

Shooting and burning pain coldness cyanosis, and atrophy of fingertips indicate reflex vasospasm, and from this and from compression of the subclavian artery there has been actual vascular impoverishment, such as gangrene of some fingers The pulse may be tardy, lessened, or obliterated and the blood pressure lowered on the affected side Blood vessels are not compressed by a cervical disc The sign devised by Adson is to sit the patient upright, tilt up the chin, and turn to that side There is then obliteration or lessening of the pulse and blood pressure

Pain is increased by drawing the arm downward or shoving it straight forward and at the same time turning and rotating the head away and bending it backward By reproducing pain and stopping the pulses by these maneuvers, and eliciting local tenderness at the site, the diagnosis is confirmed Roentgen films aid if they show a cervical rib, large seventh transverse process, or the long neck type.

Treatment. Conservative posture treatment if first tried, holding the head back, exercising to raise the shoulder girdle, and keeping the arm supported by a sling or pillow, may be successful, if not, operation is indicated Through a local collar incision the cleidomastoid muscle is retracted inward and the plexus is uncovered by working through the cervical fascia Care is necessary to guard the dome of the pleura the phrenic nerve which rides the scalenus anticus muscle, the subclavian vein in front which this muscle separates from its artery, and the vertebral vessels as they enter the seventh transverse process

The plexus and subclavian artery ride the first rib separated by its tubercle and emerge from between the scalenus anticus and medius muscles With a finger under the former, the structures contributing to the pressure are explored The muscle is usually hypertrophied and in some cases from spasm from a lesion higher up It is more thorough to remove a segment from it than merely to do a tenotomy This may

be sufficient even if there should be a cervical rib, but if it is seen that pressure from the rib itself is possible, this, too, should be removed with a rongeur, disarticulating it between the seventh and eighth nerves and being careful also to remove the ligament which extends from its tip forward to the first rib

Hyperextending the arms squeezes the artery between the first rib, clavicle and the pectoralis minor muscle obliterating the pulse even to an occasional gangrenous finger tip, as shown by Wright who found that in 92 6 per cent of normal soldiers hyperabduction of the arms as in sleeping obliterated the pulse

PECTORAL GIRDLE

Paralysis of Scapulothoracic Muscles

These muscles are essential for stabilizing and moving the scapula, which in turn supports the arm. Also, the portion of the spine opposite the paralyzed muscles (trapezius and rhomboids) is drawn over by the unopposed muscles until it is concave, especially on the paralyzed side Particularly important for the arm are the trapezius, serratus anticus, and the rhomboids with the levator anguli scapulae.

Trapezius In paralysis of the trapezius muscle the shoulder droops and rotates outward. There is some difficulty in raising the arm The levator anguli scapulae is a poor substitute for the upper portion of this muscle. Fascial bands have been placed for support for the drooping shoulder and correction of the spinal curve, extending from the spine of the scapula to the spines of the cervical vertebrae and to the neck muscles near the spine, with definite improvement.

In one personal case of paralysis of the trapezius muscle in which the spinal accessory nerve had been severed in draining an abscess a year previously, excellent function returned after suturing this nerve.

Serratus Anticus. In paralysis of the serratus anticus muscle the scapula wings and displaces backward as the patient leans forward on his hands against the table. The arm cannot be raised in abduction beyond the horizontal as the lower end of the scapula swings inward Trauma in carrying a load on the shoulder has injured this nerve. It is difficult to make a brace that will hold the scapula in place. In the one shown in Fig 471 a cupped metal plate holds the scapula. Surgically the scapula has been held in place to fair degree by fascial grafts from its tip forward to several ribs and to the pectoral muscle. Darling slung the scapula by three fascial strips from the spinous processes of the cervical and thoracic spines Ober, Tubby and Durman prolonged the pectoral muscle or its clavicular part by a fascial graft. This may be looped through a hole in the lower angle of the scapula.

Rhomboid and Levator Anguli Scapulae. In rhomboid and levator anguli scapulae paralysis the scapula displaces downward and outward from the spine, rotating outward. Improvement in these cases has been gained by fastening the vertebral border of the scapula by several strips of fascia to the spinous processes and the spinal and latissimus dorsi muscles, or, as done by Lowman, to the opposite scapula.

The fascial transplants in the above operations have a bone attachment at one end and muscle at the other, and are placed in the concavity of the spinal curve to help straighten it. This subject is still experimental, though worth while clinical improvement has been reported by Frank D Dickson and Lowman in their pioneer work.

Dislocation of Acromioclavicular Joint

Fresh dislocations, if held in place six weeks, heal well. Internal fixation has been attempted by placing a Kirschner wire through both bones. This is difficult and unsatisfactory even when both ends of the wire are turned back or if the wires are crossed. A 1½ in. to 1¾ in. screw with

broad head and wide flanged low-pitched thread was placed through a drill hole in the clavicle and screwed through two cortices of the coracoid process with good results in 17 cases by Bosworth External fixation is done by strapping the clavicle down on the rest of the shoulder girdle The strap loops around the chest, crosses over a shoulder pad to press the clavicle down, and then loops under a right angle elbow cast The latter is built high in the axilla under a fold of felt and is supported by a sling

Old Dislocation Mumford recommended removal of the outer end of the clavicle with or without a fascial transplant

A B C

D E

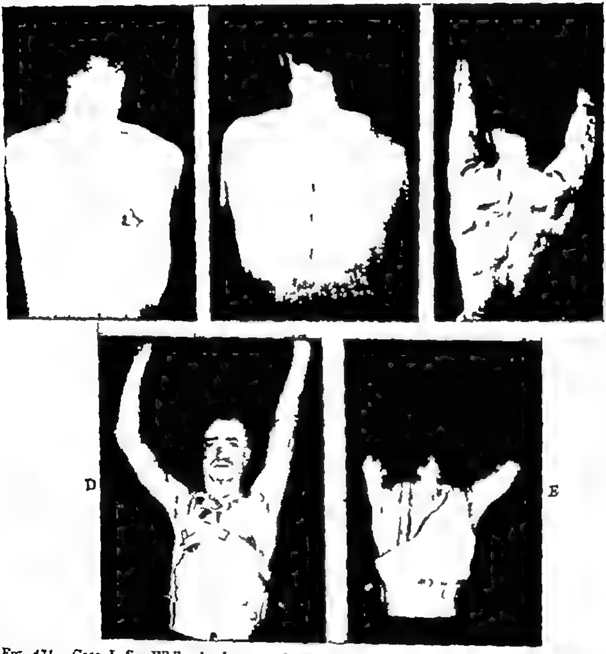


FIG. 471 Case J S. While shoving on a barrel he felt a tear He ruptured his serratus anterior muscle from the scapula, which left him without the ability to raise his arm more than to just above the horizontal.

(A) Showing deformity of winged scapula.

(B and C) Through a posterior incision the muscle was resutured in place. Photographs show correction of deformity and disability

(D and E) Special brace for winged scapula which holds scapula in place making it possible to raise arm. Used in this case postoperatively The straps at the sides in (D) extend down to the crotch.

about the coracoid process and clavicle. Others reported some weakness following In the old untreated cases where the torn conoid and trapezoid ligaments no longer hold the clavicle down on the coracoid process, there may be pain and disability on lifting When the arms are folded the clavicle rides out conspicuously over the acromion

The following is a new modification of the method of repair formerly described by the author, consisting of reproducing the ligaments of the joint itself and the conoid and trapezoid ligaments by one strip of fascia as a graft. While the fascia is healing the bones are temporarily held in place by means of removable stainless steel wire.

Through an incision straight across the shoulder, sufficient skin is undermined to expose the outer ends of the clavicle and acromion. Three holes 5 mm. in diameter are drilled. Hole 1 penetrates the tip of the acromion slightly in front of the center of the joint, hole 2 penetrates the outer end of the clavicle slightly behind the center of the joint, and hole 3 penetrates the clavicle at the outer end of the trapezoid ligament.

The upper surface of the bones is then denuded of periosteum in line with the holes and at the posterior border of the clavicle for bony contact with the fascial graft.

A strong piece of catgut on a curved

A B C

D E F

FIG 472 For dislocation of acromioclavicular joint method of placing 12 inch graft of fascia lata to reproduce conoid and trapezoid ligaments.

(A) Showing the anatomy of the conoid and trapezoid ligaments, the position of the three holes in the bones and the fascial graft (indicated by rubber tube) in place but not yet drawn up.

(B) Showing fascial graft (indicated by rubber tube) in place and sutured as seen from in front.

(C) Posterior view of same.

(D) Superior view showing extra reinforcement of joint capsule.

(E) Inferior view

(F) Showing patient on whom this operation was performed six months previously Although he is lifting a heavy anvil no difference can be detected in his two acromioclavicular joints. The original anatomy is reconstructed and the function is normal. (Courtesy Surg., Gynec., and Obstet., 46 563 April, 1928.)

needle, following the course along which the strip of fascia is to be placed, is then threaded down hole 1 and up hole 2, then passed back of the clavicle and with a Deschamps carrier is passed around under the coracoid process, down its inner side, up its outer side, and finally up through hole 3 The carrier fits around the coracoid process well if the diameter of the curve is 1½ inches and its point projects ¾ inch beyond the semicircle

This piece of catgut with a loop in its center is used as a pilot guide first to place a wire and then a fascial graft. Guided by the catgut, which is used as a shuttle, one piece of No 22 stainless steel wire is placed down hole 1 and up hole 2, to hold the joint together, and another piece of the wire is made to encircle the clavicle and the coracoid process These wires, after tightening and kinking in a certain way, will hold the bones in place while the fascial graft heals, and then are withdrawn from the outside

A strip of fascia lata, 12 inches long and

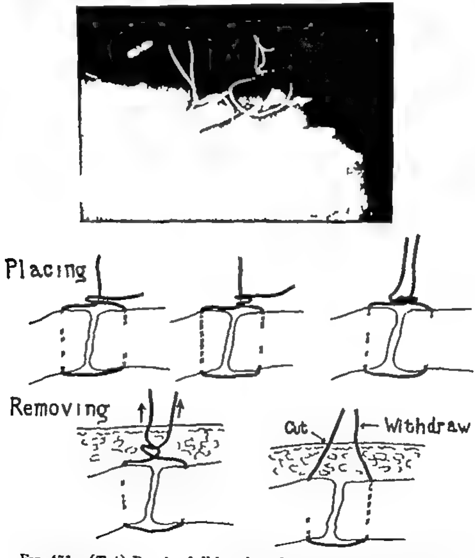


Fig. 473 (*Top*) Repair of dislocation of acromioclavicular joint using a long strip of fascia lata so placed as to reproduce the conoid and trapezoid ligaments.

To hold the bones in place while the ligamentous graft is becoming strong two loops of stainless-steel wire are used so placed that they are removable.

(*Bottom*) Method is placing stainless-steel wire so it is removable. This kink is useful in holding fractures and dislocations. To remove after three or more weeks a pull on each wire straightens out the kinks and the wire is easily withdrawn.

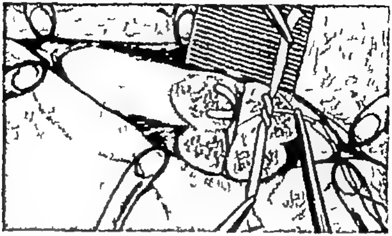


FIG. 474 Operation for dislocation of sternoclavicular joint (Bankhart's method)
The ends of the fascial strip have been brought through holes in the sternum and tied and are being held tight by an assistant while the surgeon sews the joint firmly with linen thread sutures. The front surface of the joint which has been chiseled and turned down is replaced over the fascia (Courtesy Bankhart A. S B., in Brit. Jour Surg 26.322 No 102 1938.)

one-half inch wide, is procured by a fascial stripper One end is cut in a long taper, caught in the loop of the pilot catgut and then drawn through each hole in turn along the course of the catgut. Both the fascial strips and the two pieces of wire are then drawn taut, holding the bones tightly in place The catgut is withdrawn. The two wire loops which have been placed previously to the fascia so as not to compress it are tightened and made fast by the special kink, shown in the diagram. The ends of the wires are then brought out separately through the skin and left there for a month. Then, by pulling on each wire, the kinks straighten out and the wires are withdrawn, leaving the now firmly healed fascia to carry on. With the wires holding the bones in place, the two ends of the fascia drawn taut are laid, crossing each other, parallel over the joint and are fastened so with a running removable suture of No 30 stainless steel wire, fastened at each end outside the skin with a shot.

Good results have been reported by many operators In some cases calcification has been seen in the coracoclavicular ligaments as it often occurs without operation, but even so the function is good.

Old Dislocation of Sternoclavicular Joint

The inner end of the clavicle in its false position may become stabilized and firm, but usually the joint slips in and out on movement, giving pain and disability The end of the clavicle will not permanently remain in place unless lashed there by a fascial graft. Lowman passed the graft centrally through a hole in the two bones, fastening the ends across the joint. Bankhart, after first chiseling down the face of the joint, as a flap drilled two holes in each bone. He looped his fascial graft through those in one bone, passed its two ends behind the joint out through the two holes in the other bone, fastened them together, and *replaced the flap over them.*

The following is a procedure found by the author to be successful through a transverse incision below the joint each bone is exposed The tissues are easily freed back of the clavicle and manubrium, and a carrier is passed around the first costal cartilage after carefully clearing it subperichon

drially to avoid the pleura A 5 mm hole is drilled anteroposteriorly through the manubrium and clavicle on each side of the joint A No 22 stainless steel wire is placed through these, later to tighten and hold the bones together while the fascial graft heals The wire is fastened just as described for the acromioclavicular joint and the ends are brought out through the skin, leaving them there for removal of the wire in a month

A piece of fascia lata 12 inches by one-half inch is passed through the hole in the manubrium, brought out from behind over the top of the clavicle, then down around under and up from behind the first costal cartilage. It is then brought up behind the clavicle, there looped over its first strand and brought out from behind forward through the hole in the clavicle The wire is first drawn taut and made fast by the special withdrawable kink Then the two ends of the fascia are drawn out tight across alongside each other *in front of the joint*, and there fastened by a removable running stitch of No 30 stainless steel wire brought out at each end through the skin and fastened by a shot Postoperatively, a loop of adhesive about the elbow, fastened to a belt of adhesive plaster, is the only restraint used

INJURIES TO BRACHIAL PLEXUS

Plexus injuries in peacetime are usually from traction, but in war they are largely

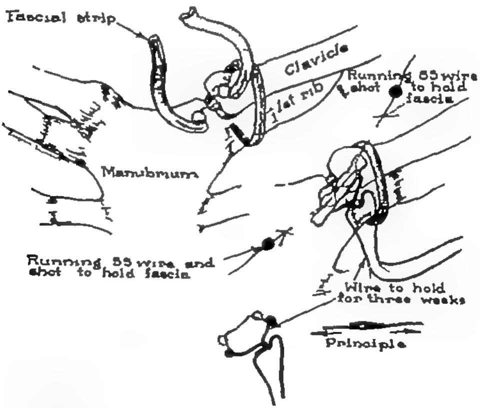


FIG. 475 Operation for dislocation of sternoclavicular joint.
Fascia lata a foot long is threaded through two holes and around the first costal cartilage in the manner shown and fastened to itself in front with a removable stainless-steel wire fastened outside the skin with two shot. The joint is kept from dislocating while the fascial graft is healing by a No 22 stainless-steel wire placed through the two holes and fastened to itself in such a way that it may be withdrawn in three weeks. On pulling each wire, both of which emerge through the skin the bends straighten out and the wire can be withdrawn. This principle is applicable for bones elsewhere.

The method has been carried out by the author with success.

from direct trauma by gunshot and stab wounds. Obstetric paralysis, or birth palsy, is from greater traction during delivery than the delicate tissues will stand Injuries by traction in later life or in adults

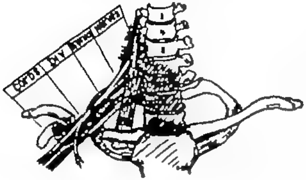


FIG. 476 The parts and relations of the brachial plexus.

are usually from sudden violence, jerking the shoulder from the head as in a collision or sudden violent jerking on the arm in any direction away from the spinal attachment. Birth palsy, differing as it does in mechanism and in the complications of deformity in growth, will be discussed separately

LOCATION OF LESIONS

The following concerns the operative findings and mechanism of production of lesion, the diagnosis having been discussed in Chapter 8

Types According to Nerve-root Grouping

When the arm is pulled downward or backward and the head away from the shoulder, the upper two or three nerves receive the strain, the lesion being of 5 6 C, or 5, 6, 7 C or more if extreme. This is the prevalent or upper type called Erb-Duchenne.

From an upward pull of the arm, similarly the strain is on the lower nerves of the plexus 8 C, 1 T, or 7 C, 8 C, 1 T or more if excessive. This lower type is named Klumpke s paralysis.

Traction directly outward or backward pulls all five spinal nerves equally, affecting several or all of them, even to a total lesion. Thus in its middle position the 7 C, which is largest and strongest, could not be affected alone.

Forward pull may rupture C 7, C 8, and D 1

In both birth palsy and adult traction paralysis the upper plexus type is commonest, the extensive type second, and the lower type the least frequent. Many traction injuries give symptoms of total lesion at first, but in the next several months commence to recover starting from either the lower or upper end of the series of the five nerves.

Location of Lesion Along Plexus

Mechanism. Traction applied to a nerve breaks first the surrounding blood vessels, then the fascial encasement and septa, and finally the nerve itself The brachial plexus with accompanying arteries and veins is ensheathed in a tube of deep fascia which protects by withstanding considerable traction. Within this tube are septa ensheathing the individual nerves and vessels for additional support. The sheath of the plexus is continuous with the surrounding deep fascia—prevertebral behind and costocoracoid in front—and in turn is fast to all adjoining bones, and these give firm resistance to traction.

The fascial sheaths about the nerves in the spinal foramina are fast to the transverse processes as the nerves lie in their bony gutters and act as snubbers (described by Stevens) as they keep the nerves from being avulsed from the cord. Passing down the plexus there are attachments to the first rib, clavicle, coracoid process, and costocoracoid prevertebral and axillary fascia, as a funnel from these structures converging down the plexus, snubbing along its length guarding against traction.

In children in whom the fascia is without strength and the nerve course in the foramina is straight out from the cord instead of from subsequent body growth away

from head inclining downward, avulsion is more common than in adults In the latter, due to strong fascial protection, the nerve lesion may be anywhere from foramina to the lower end of the axilla As the arm is pulled the first strain is on the parts joining the arm and shoulder girdle to the trunk, then on the fascia about the plexus and finally the nerves themselves

The site of lesion depends on several factors. The point of maximal strain varies with the position of the arm and the direction of the pull The arm may be pulled forward, backward upward, or downward placing strain on fascia or nerves at different levels. Distally the nerves of the plexus are smaller and are less snubbed Proximally the cords and trunks are larger and stronger Still farther proximally the nerve roots are again smaller, but because of the greater distance are better snubbed The part which is the weakest and on which there is the most strain breaks first, and so on in series. When, however, the velocity and strength of the force is terrific these rules may mean little and the point of yielding may be at any site from foramen to emergence from axilla.

FIG. 477 Complete brachial plexus palsy

Six months previously while riding a motorcycle he rammed a truck evulsing from the cord C 6 C 7 C 8 and T 1 and reducing the C 5 to a ragged cord.

AVULSION Avulsion from the cord or injury within the spinal foramen is important, as it is irreparable. It is indicated by involvement of the dorsiscapular and anterior thoracic nerves that penetrate the scalenus medius muscle and supply the rhomboid, levator scapulae, and serratus anterior muscles Avulsion is decidedly more frequent in the lower type than in the upper, and in birth palsies more than in adult. Stevens, in a wide tabulation, found it not common. In my small series it was diagnosed in two-fifths of those not operated upon and verified in three of the nine operated upon, the roots avulsed being as follows Age 4—7 C, 8 C, 1 T, age 21—7 C, 8 C, 1 T, age 32—1 T

RUPTURE. A frequent site of the lesion is just outside of the *foramina*, especially in 5 and 6 C. If so the external rotators of the shoulder and the supinator longus will be paralyzed, as well as the deltoid and flexors of the elbow Often many nerves both above, behind, and below the clavicle are involved. In a fair number the lesion is in the nerves where they emerge from the plexus, the most vulnerable single nerve of these being the circumflex in the vicinity of the teres major muscle In a personal case the musculospiral alone was torn apart at the subscapularis

DIAGNOSTIC POINTS (Fig. 285) *If* involvement of the external rotators of the shoulder (supra and infraspinatus) does not accompany paralysis of the deltoid and of flexors of the elbow, the lesion is farther down the upper trunk of the plexus between the branching off of the suprascapular nerve and the posterior division. In this case, if the flexors of wrist and pronators of the forearm are paralyzed, the lesion is in the

FIG. 478 Case C. G., aged 8. Lower brachial plexus palsy
At 13 months he fell out of a car which left the whole arm limp for six months. Now extensors of wrist and fingers work, but of flexors only the flexor carpi radialis and some of the pronator teres are working All intrinsic muscles are paralyzed Anesthesia is over the ulna, two-thirds of the hand and a strip of forearm.
Lesion includes C 8 T 1 most of C 7

lateral cord beyond where the branch from the seventh nerve joins it This spot is just where the three branches join to form the posterior cord of the plexus that is, at the beginning of the three cords and is fairly uniformly 2¾ inches from the carotid artery (Linell) Of the two branches to form the median nerve, the upper supplies the flexors of the wrist and the pronators, and the lower the flexors of the fingers and the outer intrinsic muscles of the thumb The lower branch thus differs from 8 C and 1 T, as these supply the intrinsic muscles of the fingers in addition. It also differs from the inner or medial cord which innervates the inner part of the flexor profundus, flexor carpi ulnaris intrinsics of the fingers, and inner thenar muscles.

From a glance at the arm one can tell if it has been pulled downward or upward, the former type being internally rotated at the shoulder, incapable of abduction or of flexion at the elbow, and with atrophy of the scapular muscles and deltoid and elbow flexors. The latter shows only the claw hand, thumb-at the-side deformity and atrophy of the flexors on the ulnar side of the forearm

Postoperatively, an arm that has long been down should not be raised high and fixed there with plaster, as the lower type of palsy occurs as it does in any nerve held on a stretch and it may, in part, be permanent.

Lesions in Traction Paralysis

There is an all important clinical difference between the lesion of a nerve that has been pulled apart and one injured by direct trauma. When a rope several inches in diameter is pulled until it breaks, as often seen on our wharves, each end presents a brush of fibers, but there is also extending for several feet back along the rope from where it broke an irregular enlargement with much fuzzy projection on the surface of broken hemp fibers. As the traction on the rope increased the fibers within it over a long stretch of the rope commenced to break, until finally at some point along the length, where the most *fibers happened to rupture, the rope parted* So it is with a nerve torn apart by traction. The lesion is over a length of several inches with broken axones and the effects of trauma throughout the length. Such a nerve will, of course, be damaged far back *from the ends, most of the axones being* parted in multiple places in addition to the site of nerve separation (Fig 479)

This explains the poor results after suturing such a nerve, unless the whole length of the injured part is first excised. It explains, too, why plexus-traction injuries in the first two years make considerable recovery In many there is actual parting of the nerves, the two ends being continuous or not by merely a narrow thread of fibrous tissue, but in most cases the nerve is found to be thickened over a distance of several inches without definite break of continuity Hence, temporary paralysis is common. Some axones are merely stretched and recover, and others grow down the continuous pathway in regeneration The common finding is a great, irregular, cicatricial,

thickened mass along a stretch of plexus of one to five inches. Some of the nerves may be affected for a longer length than others, and some show actual separation of their ends for one to 2½ inches. The whole the amount of spontaneous recovery can be judged At operation soon after accident, the degree of reactive thickening that will take place in the nerves will show then, judging from viewing other nerves injured

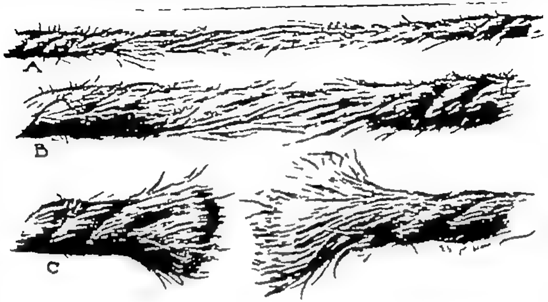


Fig. 479 A nerve and a rope act alike when under traction. Axones (i.e., rope fibers) break all along for quite a length until finally one point is weakest and there the nerve or rope pulls apart.

Suture of the ends of such a nerve is useless as axones have multiple rupture. If though, the whole enlarged cicatricial segment is excised and the good ends sutured regeneration follows the same as after suturing a severed nerve. This explains many poor results after suture of a ruptured brachial plexus.

region is very vascular from trauma, and the mass is firmly adherent to the blood vessels and surrounding tissues In many cases aneurysms have been found from injury to accompanying vessels. It is usually described that the above findings are due to hemorrhage about the plexus pressing on the plexus, making ischemia and necrosis, which as an explanation seems untenable.

Treatment

When to Operate

Operation may be done at any time after the initial shock with advantage of easier dissection, freedom from cicatrix clarity of the physical damage, and the opportunity of suturing early Unless the lesion is extensive, however, the case may be one in which recovery will take place spontaneously For this reason it is usual to postpone operation until in six months to a year by traction, as swelling and congestion It is better to operate sooner than later, because fibrous degeneration of the muscles is continuous and after two years greatly reduces the chance of recovery Even after being sutured the nerves take a year to regenerate the length of the arm to the hand muscles There is so much relaxation of the scapulohumeral muscles that the arm should be lifted by a socket molded under the flexed elbow This in turn is supported by a brace against the iliac crest held there by a belt

Operation

Through a collar incision in line with the creases and over the middle of the plexus undermining broadly beneath the platysma, the cleidomastoid muscle is retracted inward and by dissecting through the fascia and cicatrix the plexus is exposed If extensive, a wide exposure will

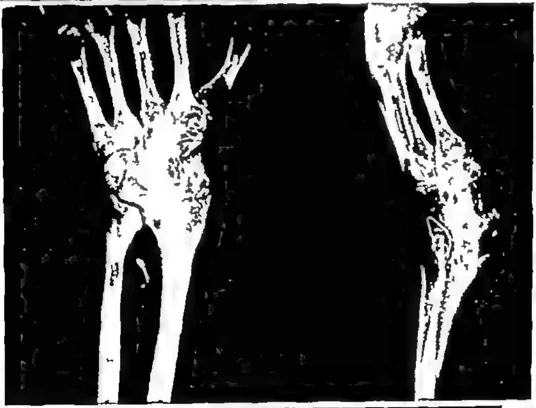
A

FIG. 480 Case P R., aged 16 As determined at operation (see brachial plexus cases) at the age of 4 the C 8 T 1 and most of C 7 nerves were avulsed from the spinal cord rendering the hand useless, the only functioning muscles being the extensors of the wrist, flexor carpi radialis and pronator teres

(A, *Top*) Useless hand at age of 16 The arm was useful only to the wrist. The wrist was arthrodesed, sparing the radioulnar joint, and the following tendons were transferred extensor carpi radialis brevis to extensors of fingers and the long extensor of the thumb flexor carpi radialis to the flexor of the thumb extensor carpi radialis longus to the flexor profundus supinator longus plus a tendon graft from the palmaris longus looped around the flexor ulnaris to give opposition to the thumb

(B *Center*) X rays of arthrodesis.

(C and D *Bottom*) Hand gained strong motion and could pick up and hold objects, becoming very useful



B

C

D

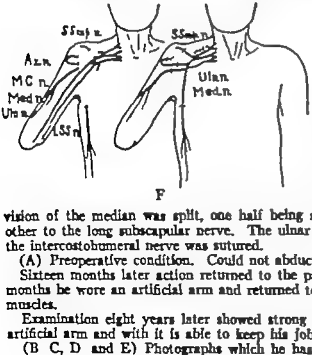


FIG. 481 Case J E. B A tree fell on his shoulder resulting in gangrene from tearing off the axillary artery and the following branches of the brachial plexus

Suprascapular, circumflex, long subscapular musculocutaneous, and radial.

On June 14 1934 the flexion contracture at the axilla was relieved and nerve supply was furnished to the paralyzed muscles, supraspinatus, infraspinatus, teres minor deltoid, biceps, and latissimus dorsi by transferring the median and ulnar nerves to the distal ends of the torn ones. The upper division of the median nerve was transferred to the circumflex. The lower division of the median was split, one half being sutured to the suprascapular at the notch and the other to the long subscapular nerve. The ulnar nerve was transferred to the musculocutaneous and the intercostohumeral nerve was sutured.

(A) Preoperative condition. Could not abduct arm. Could only internally rotate and adduct.

Sixteen months later action returned to the paralyzed muscles, starting at eight months. By 16 months he wore an artificial arm and returned to work. Function returned to all of the paralyzed muscles.

Examination eight years later showed strong motion at shoulder in all directions. He wears an artificial arm and with it is able to keep his job in the State Department of Fish and Game.

(B C, D and E) Photographs which he has sent. The legs of the chair must be resting on a table.

(F) Showing on left the torn nerves and on right the transferred ones.

be necessary as every advance along the plexus is accompanied by bleeding. High surgical skill is necessary If the lesion extends below the clavicle, this is severed in a dovetail manner and the pectoral muscles detached with their bony insertion and reflected downward For this the incision must be continued from its outer end forward along the creases to the axilla. Removal of the clavicle is justifiable.

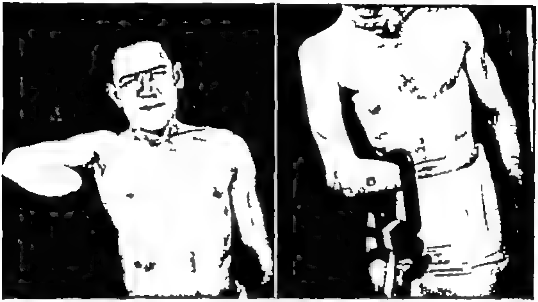


FIG. 482 Case J M. Triceps prolonged by tendon graft to tuberosity of radius for paralysis of flexors of elbow This is Case J M. of series reported of repair of brachial plexus in which all 5 nerves were sutured.

(A) Abduction through suture of brachial plexus.

(B) Strong flexion of elbow (can lift 20 lb) through triceps transfer Note shadow of triceps. Triceps was elongated by a 1½-inch tendon graft from an extensor of the wrist. Regenerated condylar flexors were also transferred up humerus. At first he tensed whole arm to flex the elbow but in 5 months the elbow flexed naturally All motions of the shoulder returned and felt natural, showing that the brain adapts to this degree.

As the plexus is uncovered, guarding carefully the subclavian and axillary vessels and dome of the pleura, the scalenus anticus with the phrenic nerve on its surface is seen in front of it and the scalenus medius behind. The topmost conspicuous nerve is the fifth, the fourth being much smaller Seven C is recognized by its large size and 8 C and 1 T by having to dissect deep and low to reach their foramina. The three trunks from 5 C, 6 C, then 7 C and 8 C, 1 T, respectively are identified and from here on the posterior division is behind the artery which has come into the plexus from below Two and three-quarters inches from the carotid marks the beginning of the cords. The first large conspicuous nerve branch leaving superiorly is the suprascapula. Farther distally the musculocutaneous and median nerves are the most conspicuous, being high and anterior

If a nerve has been avulsed and the next nerve torn from its stump just beyond the foramen, both nerves should be sutured to this stump If the nerve, or nerves, show a neuroma above and a narrowing and cicatrix for several inches below, this injured portion should be excised to as far in each direction as until good axone bundles show and the ends should be joined by suture. Usually on cross-sectioning such a solid cord, few or no axone bundles can be seen. If in the length of injured nerve there is merely thickening freeing it from cicatrix and slitting its sheath may be sufficient. We can, in the brachial plexus, overcome a

gap of four inches when necessary by freeing the nerves down the arm, removing the clavicle or a segment of it, cutting the scalenus anticus muscle to allow the plexus to bowstring forward When the gap in the plexus is great, it should be overcome by shortening the humerus Radical methods are justifiable considering that a hand without nerve supply is useless. The head and shoulder are drawn together by fastening a sling under the axilla to the plaster-of Paris headband The wrist should be fastened to the other shoulder After a month the restraining straps are lengthened so gradually that the nerves will grow long enough without stretching.

Prognosis

In cases of direct injury by gunshot, stab wound, etc., the prognosis after excision and suture is as good as in any high nerve suture—return of about 80 per cent of function. Nerves parted within a foramen or avulsed from a cord are hopeless unless joined to another nerve stump The prognosis after suture of nerves which have been torn apart is not nearly so good because, as explained above, the nerve has been damaged for a distance of several inches (up to five in some cases, but usually two or three) Many reports after suture of these have told of discouraging results, and many surgeons after the long and tiresome operation have hesitated to excise the cicatricial nerve segments far enough to reach good axone bundles before suturing Taylor (1920), in addition to his wide experience in operating on 70 cases (later 94) of birth palsy, reported suturing 14 plexuses in adults, with results not so good as those obtained in the former cases, but still with considerable improvement.

Report of Personal Cases

My own experience is limited to ten cases of traction operated upon, none of which were of birth palsy and one case of rifle wound In three there was no improvement In two of these (P R and S M) there was avulsion from the cord The other (T F F) was a late case three years after accident, and two operations had already been done on the plexus One was operated on too recently for a result In the other six there was enough improvement resulting from the operation to have made the procedure worth while In most, sensation returned throughout the limb and function of most of the muscles about the shoulder and the biceps and triceps returned to varying degrees, but enough to be useful In only one of these cases of suture did muscles below the elbow recover When, however, voluntary movement recovered in shoulder and elbow, amputation could be done as low as through the forearm, resulting in a useful limb In one case an arthrodesis was made at the shoulder after recovery of latissimus, pectoral, triceps, and biceps muscles. In one case the suprascapular, long subscapular, circumflex, and musculocutaneous nerves had ruptured. The arm had been amputated supracondylarly The median and ulnar nerves were withdrawn from it, split and sutured into the distal portions of the above four nerves with such good recovery of all of the muscles supplied by these nerves that he now handles an artificial arm well and works steadily (Fig 481)

The table in the following two pages shows the lesions and results of the eleven cases personally operated upon.

Obstetric Paralysis

Mechanism

The site of lesion is more uniform than in adults. Most cases are of the upper type from tear of 5 and 6 C at the suprascapular nerve. Some are complete plexus injuries and a few are of the lower type. Upper type tears occur in either vertex or breech presentations, in the latter from hooking the fingers over the shoulders and

Case	*Age*	*Lesion*	*Operation*	*Result*
N H	17	5 6C ragged for 2 inches near foramen	Excised and sutured	One year later our last opportunity to check this patient, there were definite signs of beginning recovery The deltoid and biceps muscles each showed voluntary motion. He raised the arm laterally 50 anteriorly 60 externally rotated it 45 and the elbow voluntarily flexed to a right angle against grav ity *none of which he could do before the nerves were sutured*
J Y	54	5, 6, 7C, posterior and lateral cords between subscapular nerve and axillary nerve at clavicle, musculocutaneous and median nerves torn apart	Excised and sutured. Axillary nerve transferred into posterior cord	Fair recovery in one year . Biceps, triceps deltoid recovered. None below elbow One previous operation on plexus
T F F	22	5 6 7 8C. All torn apart beyond fora mina. Three-inch gap	Excised and sutured. Proximal axillary nerve transferred to distal pectorals	Little improvement but case was three years old and had had two operations on brachial plexus. Sensation recovered throughout. Recovery of supraspinatus, latissimus and part of pectoral
A. E. L.	32	5 6 7 8C, 1T 1T avulsed. Horner's syndrome. 5 to 8C torn apart near *foramina. Cicatrix from spine to arm* for 3 inches	Excised and sutured	Result well worth while. Sensation throughout. Some sympathetic pain which left. All muscles returned down to elbow except deltoid Therefore, arthrodesed shoulder and amputated through forearm. Recovery of latissimus, pectoral, biceps, and triceps. Wears artificial arm
J M	19	5, 6 7 8C, 1T Torn apart near fora men. Maximal distance of cicatrix 4 inches	Excised and sutured	Enough improvement in two years to be well worth while. Triceps, supraspinatus, infraspinatus, and pectorals recovered. Abduction to 70 Pronation of forearm and a little flexion of fingers. Sensation to fingertips. Later he was given flexion of the elbow by transferring the tendon of the triceps muscle (see Fig 482) He could then lift 20 pounds and use a light artificial limb

S. M	20	Musculospiral torn apart just above first subscapular nerve. Reduced to narrow scar for 2 inches to below axillary nerve, but sparing subscapular and axillary nerves	June, 1943 Stripped up axillary and subscapular Excised 2 inches of musculospiral and sutured	Two years later at last visit triceps and extensors of wrist were strong Extended fingers completely when wrist was straight. Thumb lacks only 2 inches of full extension. Anesthesia gone
M S	21	6, 7 8C, 1T all avulsed from cord. 5C ragged	Excised and sutured the fifth nerve only	No postoperative records as yet
P R.	4	7, 8C, 1T avulsed	None	No improvement. When grown arthrodesing wrist and transferring tendons gave a useful hand. (Fig. 480)
F B	36	8C Thick near foramen	Freed 8C	Recovered well in sensation and intrinsic muscles of hand
J E B.	24	Four nerves torn apart high in axilla suprascapular long subscapular axillary musculocutaneous	Median and ulnar nerves withdrawn from arm stump (supracondylar) split and transferred into four nerves	Very good. All muscles supplied by four nerves recovered well. Uses artificial arm well
C. D	35	Rifle wound outer and posterior cords above subscapulars except a tiny strand to the median nerve	Upper four posterior divisions were sutured together and then to posterior cord. Outer cord sutured	Only six months have elapsed but all muscles down to elbow already show some action

Summary: Eleven cases operated upon
Three cases not improved (two avulsion and one case three years old with two previous plexus operations)
Eight cases improved enough to be worth while.
No muscle below the elbow recovered except in three cases, of these one was of freeing 8 C intrinsics of hand recovered In one of suturing the total plexus some pronation and a little flexion of the fingers. In case S M of posterior cord palsy all muscles were recovering
In eight cases nerves were actually pulled apart, three of which were avulsed from cord.

in each from pulling the head and shoulders apart. The tear is often near the foramen, but may be farther down, or may be an avulsion The lower type is from traction on the arms overhead This usually avulses the nerves and is likely to damage the shoulder

Symptoms

At first little is noticed but a flaccid arm with no movement if severe, or only a little in fingers and wrist. Swelling over the plexus is absent in mild cases and with avulsion, but comes later in the severe ones. Most cases appear to be severe at first, but rapidly recover—some in one to three weeks The majority recover, though if not within six months there will be partial disability Most recover in three or four months, and some in eight months. The residual may be paralysis of deltoid biceps, external rotators of shoulder, supinator longus, and sometimes triceps. The internal rotators are strong, and being unopposed rotate the arm until the palm faces backward. The arm hangs and has no or little power of abduction In the lower or Klumpke type only the intrinsic muscles of the hand, adductors of wrist, and ulnar flexors of fingers are affected, and in some the thumb intrinsics are spared. Horner's syndrome usually means bad prognosis because of avulsion.

Shoulder Changes and Deformity

The shoulder may be simultaneously injured, but in most cases a deformity comes later after three to six weeks due to muscle imbalance, and it increases with growth Strong internal rotation with no opposition or support behind allows the head to roll inward, dislocating posteriorly In such severe cases due to absence of the humeral head in the usual place, the coracoid and acromion processes grow long and hook downward The arm is at the side. Abduction beyond the horizontal is impossible Due to excessive internal rotation the hand cannot reach the mouth or head without awkwardly elevating the elbow Supination is half limited The elbow is slightly flexed and with some varus. Flexion may be limited from the stronger pull of the triceps and from some forward luxation of the radial head, due to weakness of supinators.

Treatment

Paralyzed muscles from the beginning should be kept in relaxation and this at the same time prevents deformities. For the common upper type the arm is kept in the oath position—abduction and external rotation at the shoulder, and supination of the forearm. At first a soft sling about the wrist attached to the opposite shoulder holds the hand behind the head until later a leather brace is applied In the lower type, a hand splint should correct clawing and hold the thumb in opposition.

Nerve Operation. If the whole plexus is involved, exploration of the nerves is advisable as early as the third month. As in adults, the earlier a parted nerve is rejoined the better is the recovery The milder cases will by then show enough recovery not to be surgical. If exploration of the plexus were harmful, which it is not, a delay of a year might be justified. Degeneration of muscles negates the value of late operations, so three or four years is definitely late. The operation is as in adults. Taylor, with the experience of 94 of these operations, 56 of which were followed, conclusively showed that the improvement gained justifies the procedure. The results in patients over three years old at time of operation, though showing much improvement, are less impressive, but when done at from one month to one year of age the reports of 16 serious cases were almost perfect in 25 per cent, great improvement in 37½ per cent, improved 12½ per cent and not improved 25 per cent. Of 13 cases two to three years old at operation these figures are 23, 54, 8, and 15 per cent, respectively

Orthopedic Operations. INDICATIONS AND PROGNOSIS The object of operation is to relieve the adduction and internal rotation contracture at the shoulder, leaving the arm free to rotate externally and to abduct

SEVER OPERATION Entering between pectoral and deltoid, in most cases the pectoral insertion is cut across first, then the tip of the coracoid with its three muscle attachments The tendon of the subscapu

FIG. 483 (*Left*) From a stab wound in axilla 12 years previously the ulnar and much of the median nerves are paralyzed Tendon transfers are indicated a pulley operation for opposition a tendon T operation for adduction of thumb and curvature of the arches and a clawhand operation for muscle balance
(*Center* and *Right*) Deformity of imbalance of muscles

In some, correction is needed for posterior luxation of the humeral head and in some for torsion of the humerus, in that the head faces backward. If the thoracicoscapular and scapulohumeral muscles are too extensively paralyzed, little can be done. The basic operation is that established by Sever Other modifications are for luxation and torsion It is done at four or five years of age and gives best results when some deltoid action is present and instead of luxation there is merely capsular and muscular contracture. Sever claims that 96 per cent are good results. They cannot internally rotate as well, but abduct and externally rotate better so the hand comes easily to the mouth. Elevation of the arm depends on the deltoid and preferably with some help from the supraspinatus. With deformity corrected, muscle action may increase.

lar muscle is severed without cutting the joint capsule and then the arm is free to abduct and externally rotate. If the acromion interferes with replacement of the humeral head, it is cut across or partially removed The latissimus dorsi and teres major, if necessary, are severed, and also the pronator teres if supination is needed. A cast is applied in the oath position followed by a brace for six months, and a course of exercises is carried out.

OPERATION FOR MILD CASES In cases where merely tenotomy of the tendon of the subscapularis muscle is necessary a simple operation used by the author is as follows With arm raised overhead, through a transverse incision in axilla, after locating and protecting the circumflex nerve, the tenotomy is easily done

OTHER PROCEDURES. Rotary osteotomy may be done two months later to correct

torsion and to give some additional abduction.

Subluxation may require open operation.

At the Sever operation the teres major may be detached, as advised by l'Episcopé, and reinserted into the back of the humerus to change its function from an internal to an external rotator

A wedge osteotomy of the neck of the scapula is done by Moore subperiosteally through a posterior incision to place the arm at a better angle.

Kleinberg reports good results in eight cases by stripping the humeral head of its muscle attachments, rotating it, and allowing them to reattach

Varus at the elbow anterior dislocation of the head of the radius wristdrop and thenar palsy may need operative correction

SHOULDER REGION

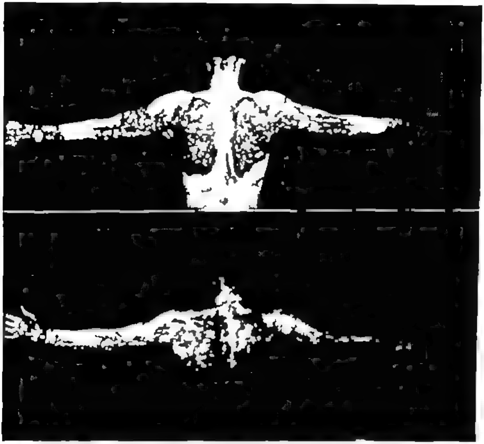
Paralysis of Deltoid Muscle

Discussion

For paralysis of the deltoid from poliomyelitis (of which it is the favorite muscle), plexus palsy or injury of the axillary nerve, as from dislocation, two procedures are available—tendon transfer and arthrodesis The latter is definitely superior, even for girls, except in a few special cases, as it gives firmer control and stronger raising of the arm, though limited to 90°

To be really successful tendon transfer needs good function of most of the shoulder muscles, including the supraspinatus and even at least partial function of the deltoid. It has the advantage of wider range of motion, even to the vertical in the

A



B

Fig. 484 (A) Keloids from burns due to the proliferation of deeper parts of dermal layer

(B) If the keloids are excised and skin grafts are applied, keloids do not reform. (Courtesy of William H. Frackelton, Lt. Col., M.C., Beaumont General Hospital.)

lateral and forward planes, which is especially applicable to some girls and non manual workers, though the motion is weaker

Arthrodesis has wide application For good results there must be strong muscle control of the scapula, particularly of shrugging and outward swinging—especially from the upper half of the trapezium and upper two-thirds of the serratus anterior—to give abduction. If, however, the trapezium is the only remaining muscle, there will be at least some improvement from arthrodesis.

FIG. 485 Arthrodesis of the shoulder three years after the Gill operation. After removing articular cartilage the acromion is denuded and thrust into a *slit in the humerus suturing periosteum above acromion to joint capsule at*tached to humerus. The humerus forms an angle with the vertebral border of the scapula of about 45 it being slightly greater in males. (Courtesy Gill, A. B., in Jour Bone and Joint Surg., 13 294 No 2 1931)

Tendon-transfer Operations

Trapezius to Deltoid Through Fascial Graft (Mayer's Operation) This procedure, first done by Stoffel in 1921, was developed by Mayer in 1927 and in 1935 by Haas The trapezius muscle, after detaching the insertion of its upper half from the clavicle and spine of the scapula, is prolonged with a fascia lata graft and fastened into the humerus at the deltoid insertion, with the arm abducted 60° The fascia is cut in a V shape seven inches long and three inches wide at the top for anteroposterior control The pull is made over the spine of the scapula as a notch cut there

Haas reports

110–180	very good	6
80–110	good	7
60– 80	fairly good	9
60	fair	6
	poor	7
		35 cases

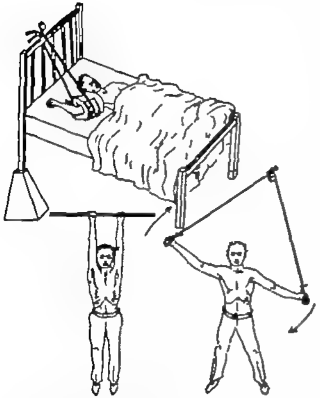


FIG. 486 Method of relieving flexion contracture of shoulder due to disuse.

When an arm is not raised for two months or more, from whatever cause such as an injured hand, it then cannot be raised. Starting with the bed method the arm is steadily raised by bandage pillow and piece of cardboard In the second week the exercises are added. Two weeks of this is sufficient and far preferable to that of forcing under anesthesia.

Transfer of Triceps and Biceps to Acromion (Ober's Operation) The long head of the triceps and the short head of the biceps were transferred around their respective sides and over the deltoid muscle *into slits in the acromion.*

Results. The best one can do in tendon transfer for deltoid paralysis is none too good, as there is insufficient muscle available for the task. Therefore, all musculature possibly available should be used, and in relaxed or luxated shoulders even a Nicola operation must be added, to hold the joint at the pivot. The special A.O.A. committee in 1942 reported that in 43 cases of Mayer's and Ober's type of operation 16 were no better, 15 slightly better, and eight very good and superior to arthrodesis. In these eight, the paralysis of the deltoid was partial.

Shoulder Arthrodesis (Gill's Operation)

The operation devised by Bruce Gill is the one of choice for its simplicity, ease, and firmness of contact. It is indicated *after the age of six and best before 12* when deltoid paralysis is complete and there is sufficient control of the scapula to transmit to the arm Growth does not interfere. The atrophied deltoid is separated from the acromion, trimmed off for an inch, and turned down. The joint capsule is opened longitudinally, sparing the biceps tendon and then its proximal half is trimmed away Both surfaces of the acromion are denuded *by chisel and both joint surfaces are gouged* out. With a chisel a wedge is cut in the greater tuberosity at such an angle to receive the acromion.

The angle of abduction should be 45 to 50°, with reference to the vertebral border of the scapula and not the trunk. There should be 15 to 20° of both flexion and internal rotation The A.O.A. committee of 1942 recommends For boys, abduction of 55° and flexion of 25° is preferable, and *for girls 45° and 15°, respectively* The hand should be able to touch the mouth

With the humerus firmly contacted to the glenoid and acromion, the fringe of the capsule is sutured to the fascia above the acromion. A cast, not a brace, is worn from three to five months until union shows by x ray After that the angle will not sag.

Much improvement in approach to the joint may be gained by making the saber cut incision, then prolonging it backwards along and beneath the spine of the scapula. Cartilage can be completely denuded and a bone graft inserted from the rear under much better vision than from the top

Shoulder Contracture from Disuse

Mechanism. This entity is so common after hand injuries that in every new examination it should be tested for, and during the treatment of hands the ability to raise the arm to the vertical should be maintained by daily practice. Quadrupeds do not have this motion, so this recent acquisition of man has such a short heritage that the arm raising muscles are inadequate to combat the huge primitive running or swimming muscles that lower the arm. The latissimus dorsi has the longest stretch of all muscles, nine inches. When this and the teres major, subscapular, and pectoral muscles and the joint capsule are kept relaxed by the arm being at the side for two months, they so contract that the weak arm raisers, especially supraspinatus, cannot draw them out and raise the arm. In apes, the supraspinatus works in a sagittal plane, but in man in the lateral. The deltoid, the only other arm raiser, is at a disadvantage in this plane.

Treatment. Many patients after their hand has long been infected lack considerable of raising their arm to the horizontal. If mild, the individual recovers by exercise. With his hand he climbs higher and higher on the edge of a door An excellent method is to hook a pulley on the picture rail. The patient stands in front with his back to the wall, holding in each hand a loop on either end of a rope which runs over the pulley With elbows straight each arm in turn draws the other arm up and back. Side-stepping toward the affected side draws the arm farther Hanging from a bar with both hands at once squares the shoulders, which makes the arm rise to a good right angle, until finally the patients can pinch their ears with their upright arms.

Resistant cases are hospitalized in a bed with its head raised 17 inches. A pillow under the arm with a bandage about it tied to the head of the bed steadily and continuously draws the arm up and mediad, as the patient slides downward. A cardboard between pillow and bandage prevents the latter from cutting The process alternated with exercise of hanging from both hands at once may require two weeks, but it is safer than forcing the arm up while under anesthesia, as this tears the joint capsule For capsular contractures the humeroscapular angle must be increased by direct manipulation. (Fig 486)

A

B C

Fig. 487 Case C. B
(A) Electrical flash burn which later caused flexion contracture of axilla.
(B) Limit of abduction.
Keloid was excised, substituting split skin graft held in place by a wax stent.
(C) Contracture relieved by skin graft.

Surgical Approach to Shoulder Some incisions prevalently used make broad keloid contracting scars as they cross the flexion creases which accommodate the upward, forward and downward movements of the arm These creases are all circumferential or transverse to the arm, so longitudinal incisions should whenever possible be avoided. The one down the front of the

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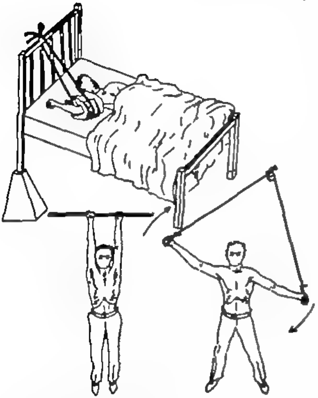

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deltoid is unnecessarily disfiguring Incisions longitudinal in the axilla or along the axillary folds make keloid contractures. A muscle-splitting deltoid incision will, if the axillary nerve in its forward course beneath the muscle is not carefully pushed down, make irretrievable paralysis and fibrous degeneration of that part of the deltoid which is in front of it.

Most shoulder exposures can be attained through transverse incisions over the top in a line of a saber cut and in the axilla from front to back accurately following the creases. These become invisible. If made long the skin can be undermined widely next to the deep fascia, and then the muscles can be separated longitudinally With the arm raised vertically over the head an incision directly across the axilla gives a perfect approach to the under aspect of the joint, axillary nerves, subscapularis, triceps, etc. The anatomy of the quadrilateral space, being reversed from the textbook pictures, should be refreshed beforehand.

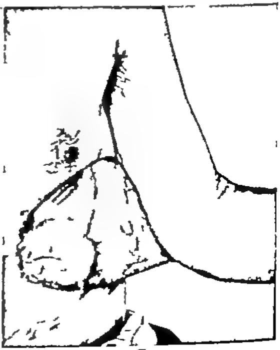
To reach the posterior part of the brachial plexus one enters through an incision across the axilla in the line of the wrinkles between the pectoral and latissimus dorsi muscles.

To reach the scapulohumeral angle for adhesions, or the Bankhart operation, the incision is made with the wrinkles from the posterior part of the axilla posteriorly The latissimus and behind it the teres major is exposed. In the field with the arm raised above the head these span the shoulder joint anteriorly and the long head of the

A

Fig 488 (A) Cicatrix at elbow
(B and C) Defect at elbow covered by direct pedicle flap Raw areas were skin grafted. (Courtesy of W B Macomber Lt Col., M C., Dibble General Hospital.)

B



C

triceps spans it posteriorly The axillary nerve is in plain view crossing the neck of the humerus to where it branches to the teres minor, and so is the subscapularis tendon inserting on the lesser tuberosity of the humerus. The two teres muscles are separated by the head of the humerus. In the scapulohumeral angle after a tear from abduction a dense scar is found including the long head of the triceps.

Tendon and Capsular Injuries

Flexion Contracture of Scapulohumeral Angle. Following tear of the inferior part of the capsule, old dislocation, or other trauma with extravasation, after which the arm has been kept at the side, cicatrix accumulates and seals across the scapulohumeral angle, preventing abduction On raising the arm, the scapula accompanies the humerus, its lower angle presenting itself unyieldingly in the axilla.

If, under anesthesia, the arm is raised while another holds the scapula to the trunk, a loud pop and tear occurs as the contracture yields. If the arm is fastened in the raised position, paralysis from stretched nerves may result. Often the contracture recurs as the rent heals, necessitating open operation.

OPERATION Approaching through the axilla, as just described, one follows up the anterior surface of the latissimus and teres major muscles in front and the triceps and teres minor behind to the humerus. The axillary nerve and vessels passing backward across the humeral neck are seen branching to the teres minor and are protected The capsule may be absent in much of its anterior inferior part, exposing the articulating surface of the head, and a tight cicatricial band may be seen spreading from the lower border of the subscapularis muscle to the torn edges of the capsule, preventing external rotation. The long head of the triceps is tight, thick, and cicatricial, and the under part of the capsule is exceedingly thick and strong, necessitating excision This is the hypertrophied torn edge of the gap in the capsule from attempt to repair, and when all is excised there is free movement Moderate abduction and exercises must be maintained

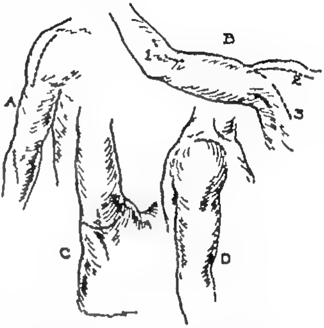


FIG. 489 Incisions, harmful and harmless.

(A and B) Incisions indicated form broad scars and contractures as they are in a *direction* at a right angle to the flexion creases.

(C and D) Incisions that give ample exposure of either side of shoulder joint, leaving very inconspicuous scars

Injury of Supraspinatus Tendon. From a single or repeated traumatism from voluntary or passive strain as in falls or impingement in abduction on the acromion process, the superior portion of the shoulder capsule is injured or ruptured. Some are from attrition in the aged. The injury may be slight and followed by lime formation in the healing. It may be a tear across its under surface only, or through full thickness It usually is across the supraspinatus tendon near its insertion, but may extend across those of the infraspinatus and teres minor muscles and present a wide gap Subdeltoid bursitis is secondary to injury of the sheet of underlying tendons, which there constitutes the capsule. The bursa takes the rub between the shoulder cuff and the acromion and coracoacromial ligament

There may also be injury, rupture, or displacement of the long head of the biceps tendon and local sharp exostoses

SYMPTOMS. There is pain at the front of the shoulder and over the deltoid region lowering When the bursa is inflamed tenderness is present throughout its area. Lime, if present, shows in the supraspinatus tendon roentgenographically, usually in external rotation, but rotating under the

FIG. 490. Case F C.
(*Left*) Flexion contracture of axilla from burn. Abdominal tubular pedicle has been attached to wrist for transportation to axilla.
(*Right*) Pedicle skin has been placed across the line of tension of the contracture.
Plastic work was done on neck.

increased by raising the arm, and tenderness is elicited at the tendon insertion on revolving the humeral head under the finger Also, a groove is sometimes felt. The supraspinatus muscle is atrophied and on either voluntary or passive activation of it pain is elicited On raising the arm, the scapula at first moves with the humerus to the end of the scapular range, before the humerus moves on the scapula. Normally both start together but the humerus moves much faster at first and the scapula later This sign is indicative, according to Codman, who developed much of our knowledge of this entity In a real tear of the supraspinatus, the arm can be raised passively but not voluntarily In moderate tears there is pain in the part of the arc just above the horizontal in both raising and fluoroscope may be necessary to find it. It may be present in the other tendons there, and is bilateral in a large proportion of cases. Lime, when increasing under pressure, is very painful, though the pain leaves if it bursts into the bursa.

TREATMENT In mild cases, desisting from lifting in motions involving the supraspinatus muscle, or resting on an airplane splint and using heat, is sufficient. If lime causes pain, needling under local anesthesia may disperse it, or bring enough blood supply to carry it away A sure method is to expose the tendon through a small incision and remove the lime from between its fibers by extensive curetting.

In ruptures of the supraspinatus tendon, surgical repair is indicated First, however,

if the arm cannot be raised passively, it should be made to do so by the method described under contracture of shoulder from disuse Then if it can be raised vol untarily, operation may be canceled

OPERATION Sufficient exposure may be gained by merely splitting the anterior fibers of the deltoid, shoving down the nerve, and presenting the tear by rotating the head of the humerus If greater exposure is necessary, as when the rent is wide or is also through the tendons of the infra spinatus and teres minor, the short transverse incision is elongated and a slice is sawed off the edge of the acromion, displaced downward with that part of the del toid and later replaced preferably with a little upward inclination To avoid im pingement against the acromion process, clearance is gained by excising that part of the acromion or cutting it across and angu lating it upward

On opening the bursa congestion or torn tendon may be seen in its floor If not, the capsule is split longitudinally and on the cut edge the repaired rent may show as being filled with grayer cicatrix. In some a partial tear may be felt by feeling the un der surface of the capsule with a blunt in strument. On finding a tear across the tendinous part of the capsule, the capsule is split back longitudinally at each side of the tear as a ribbon When the insertion of the infraspinatus is included in the tear, the severed tendons are drawn posteriorly and must be replaced With an Allis forceps on the torn edge, the muscle can with an elastic feel, readily be drawn down for an inch. The tendon border is freshened and inserted by sutures on a bone needle under a chipped up slab of greater tuberosity The sutures are tied when the arm is abducted This position is maintained for a month by an airplane splint, until the time when the arm can be voluntarily raised from the splint. The results from this operation are excellent.

Injury of Tendon of Long Head of Biceps

Discussion This tendon frequently ruptures from excessive muscular or passive strain and in the aged often fragments and wears out from attrition The belly of the biceps is conspicuously spherical and dis-

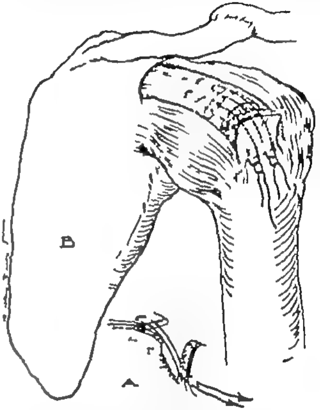


FIG. 491 Repair of ruptured tendon of supraspinatus. When the ruptured tendon is split well up from the capsule it can be drawn down freely Its end is buried in the greater tuberosity tying the permanent stainless-steel wire as the arm is extended.

placed down the arm, leaving a sulcus where the tendon formerly was Flexion of the elbow is weaker Shoulder action is af fected only if there is additional injury to the tendinous joint capsule.

In the shoulder joint the head of the humerus, moving in the glenoid cavity, is like one saucer moving in another The scapulohumeral muscles, excepting the del toid, attach around the periphery of the head and by their coordinated action tip the head in all directions and also snug up the joint and hold the head in pivot posi tion in the glenoid This pivot-centering

There may also be injury, rupture, or displacement of the long head of the biceps tendon and local sharp exostoses.

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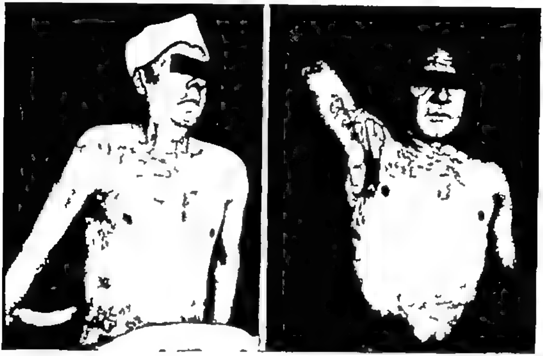

Fig 490. Case F C.
(*Left*) Flexion contracture of axilla from burn. Abdominal tubular pedicle has been attached to wrist for transportation to axilla.
(*Right*) Pedicle skin has been placed *across the line of tension of the contracture.*
Plastic work was done on neck.

Treatment In mild cases, desisting from lifting in motions involving the supraspinatus muscle, or resting on an airplane splint and using heat, is sufficient. If lime causes pain, needling under local anesthesia may disperse it, or bring enough blood supply to carry it away A sure method is to expose the tendon through a small incision and remove the lime from between its fibers by extensive curetting

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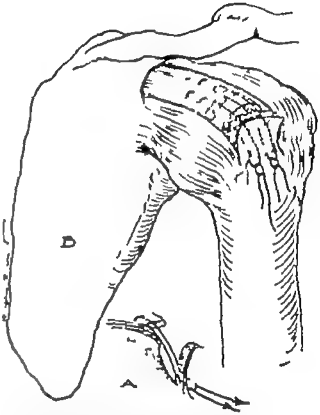

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action allows the larger thoracic humeral muscles and deltoid with trapezius to act on the arm The long head of the biceps helps in centering the pivot.

Rupture of the tendon of the supraspina tus interferes with arm raising, but rupture of the long head of the biceps does not. Many people show the latter without shoul

It is easy to reconstruct the long head ten don by running a fascial graft from the muscle up through the bicipital groove on past the normal glenoid insertion to be looped over the clavicle and back again to also be attached to the muscle. This I have done with success but the former method is satisfactory and simpler If shoulder

FIG. 492 Case J S
(*Left*) Flexion contractures from burn. Cannot abduct arm.
(*Center* and *Right*) Pedicle graft from abdomen to wrist to axilla allows raising of the arm. Neck was zigzagged.

FIG. 493 Case D S. A truck rolled over him rupturing from its insertion the left pectoral muscle, resulting in weakness in the motions of the arm that should be supplied by this muscle.
(*Left* and *Center*) Showing the deformity
(*Right*) Pectoral muscle reattached to its insertion by braiding a broad strip of fascia lata into the muscle and attaching it by removable stainless-steel wire to humerus.

der symptoms. If, though, the supraspina tus is injured and the biceps is injured also the disability is greater, as the biceps fur nishes some pivot-centering and joint-snug ging action. Conversely, if the long head of the biceps is ruptured and there is diffi culty in raising the arm, there is also injury to the tendon of the supraspinatus or supe- rior part of the capsule.

Treatment. For rupture of the long head of the biceps it has been found to be sufficient merely to fasten the distal portion into the bicipital groove or into the tendon of the short head on the coracoid process.

symptoms are present, the tendon of the supraspinatus should be exposed for the real trouble.

For luxating biceps tendon slipping forward over the lesser tuberosity on ab- duction and external rotation, fixation in the bicipital groove is sufficient.

Suture of Tendon of Pectoralis Major

Rupture from muscle action and direct trauma may be repaired by strips of fascia lata as grafts, attaching them into the mus- cle by weaving and to a spot chipped up on the bone by removable stainless steel

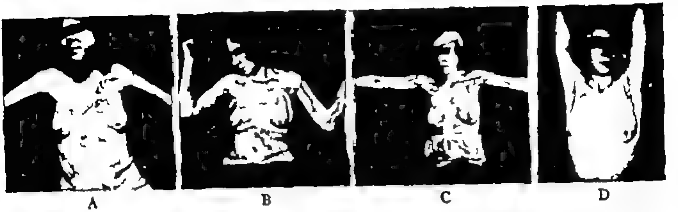

FIG. 494 Case G M. Her dress caught fire resulting in disfiguring burns and inability to raise arms.
(A) Flexion contractures axillae: Tubular pedicles have been made.
(B) Pedicles are being waltzed to axillae Some keloids have been removed from arms.
(C) Intermediate stage. Pedicled skin crosses axillae.
(D) Keloids have been excised in stages. Lines of tension have been broken by pedicled skin.

wire, through drill holes and on through the skin to a bolster (Fig 493)

RECURRENT DISLOCATION OF SHOULDER

The usual dislocation through the anterior part of the capsule, when reduced does not recur A recurrent dislocation is supposed to be produced when the humeral head is jammed forward by a blow on the back of the shoulder or on the point of the elbow when the arm is in the backward position It is usually due to a congenital loose jointed condition Common findings are tearing of the glenoid labrum or front ligamentous capsule from the anterior glenoid lip, glenoid edge worn away from repeated dislocations, and a roughening or groove posterior in the humeral head. Any of these may be absent, but there is always a laxness of the capsule which should hold the humeral head in the glenoid from a loose capsule or from lax muscles Tears in the anterior capsule have been reported and sometimes the subscapular bursa which appears as a hole has been misinterpreted for a tear The operations commonly used are of Henderson Nicola and Bankhart.

Henderson's Operation

Through a curved transverse incision from behind, the greater tuberosity of the humerus is drilled transversely and the acromion longitudinally, making the four openings wide apart for better anteroposterior stability For a ten inch suspensory graft, a half thickness of the peroneus longus tendon is selected in preference to fascia lata because of greater strength. This is passed through the hole in the humerus from the rear, each end is brought out through the deltoid muscle, and the other end is similarly passed through the acromion, the two tendon ends being fastened to themselves in front. Henderson recently reported 91 per cent successes in 51 patients

Nicola's Operation

Through a longitudinal incision after detaching and reflecting the anterior margin of the deltoid, the tendon of the long head of the biceps is cut across an inch below the bicipital groove, which is then slit through. A one-quarter inch hole, not larger, is drilled through the humeral head in the direction of the biceps tendon, entering just below the transverse humeral ligament one inch distal to the lesser tuberosity and emerging through the center of the head one-half to three-quarters inch from the articular border (less than one-half inch causes dislocation on abduction) The tendon is scraped, drawn out through the hole, and fastened to the transverse humeral

ligament, with the arm abducted to a right angle. The elbow is flexed and the two ends of the tendon are united A Velpeau bandage is worn three weeks Many results have been excellent but many recurrences have been reported with instances of fraying of the tendon downwards and leave the subscapularis tendon inserted into the capsule or left free. It is claimed that excessive scar tissue in the neighborhood effects the cure.

Staples have been proposed to fasten the labrum to the *glenoid lip* The labrum, however, is a tiny structure which seems to have comparatively little importance.

FIG. 495 Cicatricial defect radiodorsal aspect of forearm. Direct flap from abdomen applied preparatory to tendon grafts and transfers. (Courtesy of L. D Howard, Lt. Col., M.C. Wakeman General Hospital.)

Bankhart's Operation

Through an anterior approach the tip of the coronoid process is detached retracting its three muscles downward, and the insertion of the subscapularis is detached The capsule is incised or there may be an opening already present The glenoid labrum is sutured in place onto the freshened glenoid *rim and the capsule is repaired.* The two detached insertions are replaced. Magnuson advises advancing the insertion of the subscapularis to tighten it. Excellent results from the Bankhart operation are reported. Many complain of the difficulty of the operation and of insufficient material to *fasten to the glenoid edge and so are content* to roughen up the neck of the scapula, chisel up or graft a shelf replace the coracoid bent

An easy method which I have done successfully is, with the arm fully raised, *to* approach through a transverse axillary incision, entering between the brachial plexus and the teres *major* muscle. A clear view is obtained of the joint where it dislocates and also of the subscapularis tendon without severing or detaching any muscle. The head may be seen to dislocate into a broad pouch medially and posteriorly to the glenoid the lip of the glenoid being bare bone, the capsule loose and redundant. The front of the glenoid is freshened by chiseling and the capsule is split longitudinally, gathered up, plicated transversely, drawn tight, and fastened to the denuded bone by removable stainless steel wire. For this two holes are

drilled through the glenoid neck using a small Steinmann pin Two Kirschner wires, with an eye drilled through one end of each and each loaded with the end of a piece of #28 stainless steel wire, are passed through the snugged up and overlapping capsule, one through each drill hole, and on out through the skin of the back where the suture is tied over a bolster This secures the capsule to the glenoid lip A pull-out wire is placed in the loop of this stitch and brought out through the skin in front for removal after three weeks.

Old Unreduced Dislocation of Shoulder

Operation for reduction is difficult and indicated only if pain and disability are great enough and the deltoid muscle is in good condition, though not if there already is painless useful motion Entering anteriorly, it is necessary to sever the pectoral and subscapular insertions and to open the capsule of the joint widely The bicipital groove is slit, relaxing and preserving the biceps tendon. The coracohumeral ligament is detached from the coracoid for later attachment to the acromion, if possible. It is necessary to detach the capsule widely from the humeral head, to clean out the scar filled glenoid cavity, and to stretch the soft parts sufficiently until the head can be reduced. Too strong leverage will fracture the osteoporotic humeral neck or indent the head

The capsular ligaments are reconstructed, if possible The Nicola operation is done, if necessary, placing the tendon in a slit to save time. If the pectoral or subscapular muscles are reattached, the head will dislocate on abduction Postoperatively, the arm is kept in a horizontal and slightly forward position in correct rotation. Considerable limitation of abduction can be expected.

Malankylosis

For this condition the shoulder should be rearthrodesed in good position, arthroplasty of the shoulder being rarely done and of doubtful practicability

Fractures of the Humerus

Fractures about the head are reduced by manipulation, but if not possible by open fixation If the fragments engage, the arm may be kept at the side in a sling If not, traction in abduction, moderate forward an

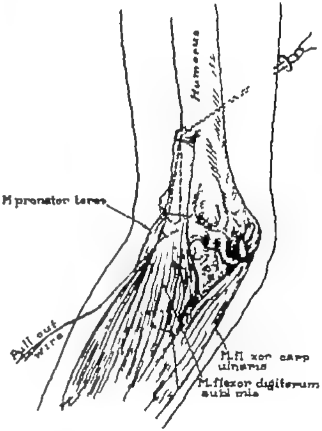

Fig 496 Author's modification of Steindler's operation for paralysis of the flexors of the elbow to furnish supination as well as flexion.

Flexor muscles in forearm are detached from the internal epicondyle prolonged by a free graft of fascia lata which in turn is attached to the outer margin of the humerus so as to give not only flexion but supination. Removable stainless-steel wire is used

gulation and with correct rotation will be necessary Fractures of the shaft are best treated by the hanging cast method with the patient always somewhat upright.

Supracondylar fractures, if not reduced early, or if put up with the elbow in acute flexion, cause Volkmann's ischemic contracture. This is avoided by the Dunlop method

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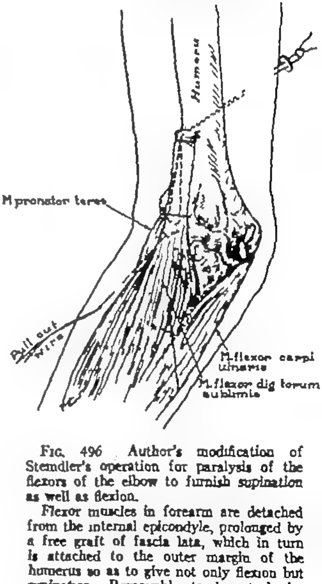

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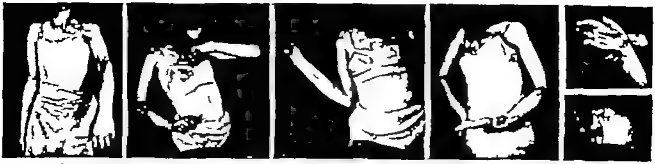


Fig. 497 Case B H., aged 22 From poliomyelitis at age of 11 neither arm could be abducted and neither elbow flexed.

(A) Showing limit of abduction at shoulder and flexion at elbow of either arm.

(B) Abduction of left shoulder after arthrodesis.

(C and D) Showing limit of flexion of each elbow and some supination after transferring the origin of the flexor muscles in the forearm from the internal epicondyle to up the external border of the humerus, using a free graft of fascia lata to span the distance. The object of fastening to the external border is to correct the pronatory tendency which is present when the internal border of the humerus is used.

(E and F) Showing improvement in opposing the right thumb by a pulley tendon transfer

used first for children. By skin traction on the forearm the arm is suspended from an upright to one side of the bed and the bed is tipped for countertraction A sling with a light weight hangs over the arm just above the elbow When callus shows, a cast is applied. Reduction held by cross pinning by Kirschner wire also prevents Volkmann s contracture

When setting a supracondylar fracture by manipulation and applying a cast the gun stock deformity is avoided by placing the forearm in pronation and externally rotating at the fracture. If good position is not obtained, the fragments are replaced by the open method Malunion may need correction by osteotomy

ELBOW REGION

In an elbow the olecranon and the two epicondyles are not so important for function. The inner condyle is essential but not the capitellum. The head of the radius may block flexion and need removal or the anterior or posterior capsule of the joint may need excision to obtain better motion

Paralysis of Elbow Flexors

Steindler s Operation. The established corrective procedure is that of Steindler, who advanced the origin of the flexors and pronators in the forearm up the humerus so they would also flex the elbow The humeral origin of these muscles was detached subperiosteally from the epicondyle, freed 1½ inches downward to the nerve supply and displaced upward on the humerus to two inches above the epicondyle, with the elbow in acute flexion.

The result is ability to flex the elbow with *fair power, depending on the strength of the* forearm muscles, but there is an increased tendency toward pronation.

Modification to Give Supination. This tendency to pronation was successfully overcome by the writer by simply prolonging these muscles of the forearm with a free graft of fascia lata, so they would reach to an attachment up the outer side of the humerus.

Transferring Triceps Tendon to Flex Elbow In this, a more *useful motion* is provided for a less useful one. The triceps tendon is detached from the olecranon and freed up the humerus until it may be brought around the outer side of the humerus under the radial nerve in a fairly straight course As the muscle is too short to reach the tuberosity of the radius, it is prolonged with a free graft of one and one-half inches of fascia lata. The attachment

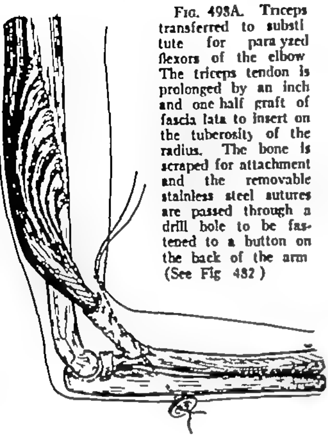


Fig. 498A. Triceps transferred to substitute for paralyzed flexors of the elbow. The triceps tendon is prolonged by an inch and one half graft of fascia lata to insert on the tuberosity of the radius. The bone is scraped for attachment and the removable stainless steel sutures are passed through a drill hole to be fastened to a button on the back of the arm (See Fig 482.)

Fig. 498B Transfer of sternocleidomastoid muscles prolonged with fascia lata to the radial tubercle to flex the paralytic elbow

Fig. 498C. For paralyzed flexors of the elbow from a brachial plexus injury a 2½ inch strip from the lower part of the pectoral muscle was detached at its lower end and transferred with its nerve supply into the biceps muscle restoring useful function.

to the radius is described under Rupture of the Lower Tendon of the Biceps. This may be reënforced with the existing biceps tendon. Strong useful flexion results (Figs. 498 and 500).

Transfer of pectoralis major insertion into the paralyzed biceps muscle has been done successfully by Clark and others to flex the elbow. He detached from the ribs the origin of the lower 2½ inches of the pectoralis major, preserved its nerve and blood supply, and passed it down the arm

to fasten it to the biceps tendon In the case reported flexion lacked only 15° extension 5°, and the patient had 40 per cent of his normal strength of flexion (See Fig 498A.)

Transfer of the sternocleidomastoid muscle may be used to flex the paralytic elbow The muscle is detached from the sternal and prolonged with fascia lata. The latter is inserted on the radial tubercle by a pull out wire stitch (see Fig 498B)

Paralysis of Triceps Muscle

The disability is largely compensated for by gravity, but as pointed out by Ober there was inability to extend the arm for crutches or to push with it or extend it upward. He utilized the brachioradialis if it were active, transferring its midportion back of the condyle to the posterior aspect of the forearm and there fastening it. The nerve and blood supply being protected, its anterior free margin was rolled back and sutured to the fascia over the triceps and extensors in the forearm, putting the elbow up in extension The result was enough to extend against gravity

Nerve Injuries at Elbow

The ulnar nerve is especially vulnerable behind the internal epicondyle from fractures, dislocations and direct trauma, and is often in need of neurolysis suture, or transposition to the front of the elbow, preferably under the hard mass of flexor muscles, where it will not be subject to surface trauma. If the nerve is not apart, the origin of these muscles is severed and then reattached for the transposition

The posterior interosseous nerve is subject to trauma of fracture and operation, where it rounds the radial neck one-half inch below the head.

The median nerve may be severed by the sharp edge of the upper fragment in supra condylar fractures.

Surgical Approaches at Elbow

Any longitudinal scar in front or back of the elbow leaves a keloid flexion contracture. Incisions should be lateral and slightly curving around the epicondyle. If either anterior or posterior to the midlateral line, the push and pull factor will make a thick contracted scar In front and back transverse incisions become invisible. The superficial nerves, antebrachial and internal cutaneous, should be avoided by undermining the skin superficial to them and then severing the superficial and deep fascia longitudinally The transverse and lateral incisions may be combined as an L. The front of the joint and humeral shaft is well exposed through the internal lateral incision keeping close to the bone and the back of the joint by longitudinal splitting of the triceps tendon and muscle.

Special Surgical Aspects

When applying casts or splints the antecubital space should always be free from constriction, lest occlusion of the superficial veins and deeper vessels start Volkmann's ischemia.

In flexion contractures in the antecubital space the traction must be broken by substituting a graft or flap of skin directly across.

After fracture or dislocation of the elbow massage, active exercise, or later forced movements or strains should be avoided, as they increase stiffness and encourage myositis ossificans traumatica. The joint is so close-fitting that reactive proliferation should be kept at a minimum by immobilization Mild motion, however, without strain or pain, prevents stiffening When ever fragments about the elbow will remain in position, treatment by a sling will keep the joint limber

Rupture of Lower Tendon of Biceps

The tendon, though less often injured than that of the long head, is avulsed from

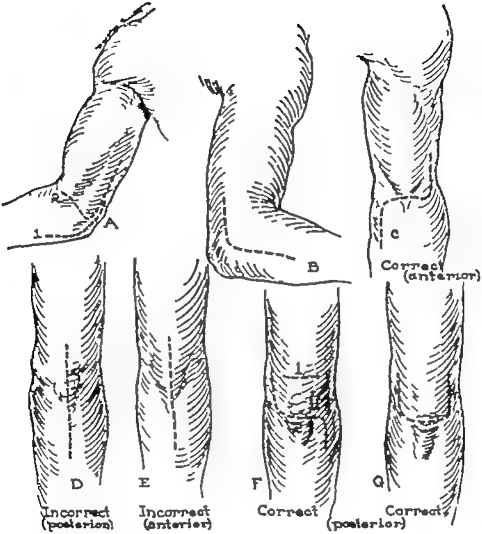


FIG. 499 Incisions for exposure about elbow
(A) 1—Exposes ulnar nerve for transplanting.
2—Exposes front of elbow joint and humerus.
(B) External lateral incision.
(C) Exposes antecubital space without making a contracture
(D and E) Median longitudinal incision in front and back of elbow which forms keloid contractures and should not be used except for arthrodesis.
(F and G) Exposure of back of elbow without causing contractures.
1—Shows incision for obtaining a graft of specialized paratenon fat from over the triceps tendon.

the tuberosity of the radius from violent direct muscular strain against resistance. Repair is awkward because of the deep position of the insertion, but can be made easy and effective by the following technic

Through a short transverse incision in front of the forearm opposite the radial tuberosity, undermining the skin a way and then opening the superficial and deep fascia longitudinally, the radial tuberosity is exposed between the pronator teres and the brachioradialis Keeping it in view with deep retractors with the forearm in supination so as to present it upward, its surface is chiseled up as a flap and the bone is here drilled through

Through a short transverse incision just above the elbow, the biceps tendon is recovered and a No 30 stainless steel wire suture with pull-out wire is placed in its end. It is passed down its former pathway and two suture ends are threaded on a straight needle and carried by it through the drill hole and on out the back of the forearm. There the sutures are drawn taut, snugging the tendon into its bony insertion as the elbow is flexed, and tied over a button. The pull-out wires on a single needle are brought out through the skin in front and left there. A posterior plaster shell holds the elbow in flexion for a month. Then the wires under the button are cut off and the tendon suture is withdrawn by the pull-out stitch.

Tennis Elbow

This painful condition comes gradually and may last from a month to a year, when over, it does not recur Tenderness is over the front of the outer epicondyle, extending slightly over the radiohumeral joint. It marks the origin of the extensor carpi brevis muscle, any activation of which elicits pain, as extending the wrist against resistance, gripping or even reaching out and picking up a light object. Considering that in gripping the extensors of the wrist strain hard to stabilize the wrist in dorsiflexion, it is clear that overstrain in gripping of the origin of the extensor carpi brevis is the etiology The lesion, fascioperiostitis, with perhaps slight tear, edema, and adhesions, is in its nature and per

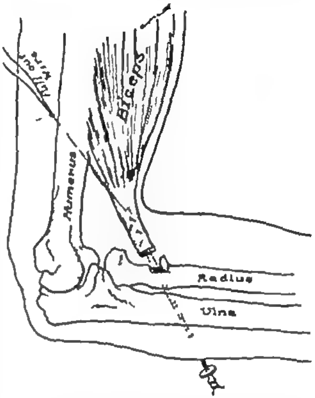


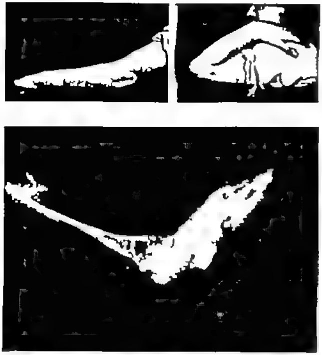
Fig. 500 Repair of evulsion of lower tendon of biceps by a simple method.

The tuberosity of the radius is exposed by retracting apart the brachioradialis and pronator teres muscles. After chipping up its surface the stainless-steel wire sutures in the biceps tendon are passed through a drillhole and out the posterior side of the limb On flexing the elbow and pulling on the sutures the tendon is snugged into place and the sutures tied over a button. A pull out wire is placed to withdraw the suture in three weeks.

Fig. 501 Mechanism of tennis elbow

Gripping is accomplished by stabilizing the wrist in dorsiflexion by the three extensor carpi muscles while the flexors of the digits contract. If done to excess the origin of the extensor carpi radialis brevis is strained and remains sore, as tennis elbow

A B



C

Fig. 502 Case A. E. H. Arthroplasty for stiff elbow from fracture Tongue of triceps tendon was turned down, humerus shaped and capped with fascia lata and head of radius was removed for rotary motion

(A) Postoperative extension and pronation.

(B) Postoperative flexion and supination.

(C) Preoperative condition.

sistence difficult to understand. Hansson demonstrated in some a reactive spur on the epicondyle. Every pull of the muscle, as in gripping, aggravates and perpetuates the condition

Of another nature is bursitis of this site, which is quite rare but real extremely painful from tension, but relieved at once by excision.

The only effective treatments of tennis elbow are rest manipulation, and operation. Rest is obtained by the constant use of a cock up splint or cast that maintains strong dorsiflexion of the wrist, preventing all pull of the offending muscle. The result is uniformly good but may require from one to five months.

Manipulation consists of strong local massage, dispelling edema and breaking adhesions, followed by a sudden jerk on the elbow in the direction of varus. Mills and Cyriax are the exponents of this method Mills made the jerk with the elbow extended and the hand and wrist pronated and flexed to have the extensor carpi brevis on a stretch, and Cyriax did it when the elbow was at a right angle with the intention of converting a partial to a complete tear He claims good results in 21 cases, averaging four manipulations and three weeks, though the time in some reached four months. Mills had good results in 33 cases Some find that the manipulation may work at first, but after that it seems ineffective.

Operative methods are to stop the pull by severing the muscle at its origin Results hardly warrant their use routinely

Arthrodesis

Following injury or infection, if it is seen that the elbow may ankylose, a choice should be made between excision and arthrodesis. If the latter is chosen, the elbow should be placed in favorable position, the consensus being a right angle. If bilateral one elbow should be at 70° to reach the mouth and the other at about 115° No one position is satisfactory for this joint, but an obtuse angle is the worst, especially at about 160°, where they usually naturally ankylose.

For malankylosis it is usually preferable to do an arthroplasty or excision, but arthrodesis at a right angle is an alternative. The bones are chiseled apart, shaped to fit, and fastened by a bone graft. This may be taken from the olecranon or elsewhere. It *may be placed on the back of the olecranon* stump and inserted into the humerus, on the back of the humerus and inserting into the ulna, or driven up through the ulna into the humerus. The head of the radius is resected to allow supination and a cast is applied for two months.

Arthroplasty

The elbow is the most satisfactory joint for arthroplasty and usually lateral stability, and good range of motion is obtained—often to an angle of 135° of flexion and lacking 20° of extension The practical function is good After infection, arthroplasty should be delayed over a year and after tuberculosis should not be done It is so unsatisfactory in children it should be delayed until at least after the fourteenth year It is not suitable for the aged

The technic was developed by Murphy, MacAusland, Campbell, and others Several approaches are used, all posterior MacAusland makes a U flap through all layers chisels across the olecranon, and turns all back in one flap Campbell made a longitudinal posteromedial incision and severed a broad tongue of triceps tendon high, turning it downward The ulnar nerve is located and protected. The back of the humerus is exposed and the forearm bones are separated by osteotome from the humerus.

The ends are carefully shaped with a chisel and smoothed with a rasp until they roughly resemble the original are amply loose, but are articulated enough for stability The radius is trimmed off in alignment. With a large flap of fascia lata, folded smooth side in, each of the joint surfaces is covered, tucking the fascia about them and making fast by sutures. Some is placed between the radius and ulna if synostosed, and a cap is fastened over the end of the radius.

According to which method is used, either the triceps tendon (if a tongue) is resutured, advancing it somewhat lower for looseness, or the olecranon is sutured back in place. The elbow is splinted at a right angle for two weeks and then exercises are commenced cautiously

Excision of Elbow

A badly comminuted elbow from injury or gunshot wound may with surprisingly good results be treated by excision at the time or later It will not be too unstable and may have good flexion and ability to lift 10 or 15 pounds The essentials are to have the two forearm bones of equal length about one half inch away from the humerus The triceps tendon should be intact with the fascia The dissection should be close to the bones of the elbow, preserving the ligamentous sleeve and all tendon attachments The humerus should be severed from 1 inch to 1½ inches from its end and the ulna just below the coronoid process including the head of the radius Early exercise through full range and work in 5 weeks restores motion and tone of muscle

If there is insufficient leverage, the biceps tendon should be transplanted further down the radius If the gap between the bones is too wide either arthrodesis or an elbow brace will be required because it is the tight biceps and triceps that give stability These may be shortened If a brace is used, it will flex by movements of the opposite shoulder, the cord coming around the outer side to prevent internal rotation

FOREARM

For dislocation of the lower radio-ulnar joint, the reader is referred to Chapter 7 Joints, for nerves paralytic, and spastic conditions and tendon transfers to Chapters 8, and 9, Nerves, and Tendons for contractures and scars to Chapter 5, Skin and Flexion Contractures.

Dislocation of Head of Radius

If only the ulna is fractured in its upper *third or only the radius in its lower*, and there is *much angulation* or overlapping the head of the other bone must be dislocated Angulation of the forearm backward, to break the ulna, dislocates the radial head from its orbicular ligament forward. On union of the ulna the radial head then blocks flexion and, being far from its pivot, and also pronation and supination Less commonly, forward breaking of the

ulna dislocates the radial head backward.

Correction requires straightening the ulna by osteotomy and open reduction of the radial head. Cicatrix is cleared away for its reception and a new orbicular ligament of palmaris longus tendon is looped about the radial neck and fastened through a drillhole in the posterior border of the ulna. The writer at the same time similarly places a No 22 stainless steel wire to maintain the bones in position while the tendon graft is healing, and removes it later under local anesthesia. In some cases, the head of the radius cannot be made to pass the capitellum and must be resected. A tendon sling should be used in either case, and also some fixation of the fractured ulna by wire or bone graft.

FIG. 503 Relief of flexion contracture at elbow by tubular pedicle graft from abdomen.

Excision of Radial Head

If the head of the radius is merely split or fractured without displacement, good pronation and supination may result. It should be treated by aspiration occasional novocain injection and freedom to move. If one fragment is displaced it should be removed, and if the head is fractured off or there is comminution with displacement the head should be removed. In children, however, excision is best deferred if possible until growth is attained—even though pronatory movement is temporarily checked.

In an old case pronation and supination may be gained by resecting the radial head, or if it is fused to the ulna by removing a *short radial segment of the neck* taking great care to avoid the posterior interosseous nerve.

After resection of the radial head, there may be some complaint of pain and weakness, as reported by King, Lewis and Thibodeau, especially if too much of the radius was removed, or if there is new bone formation. At the wrist the radius becomes relatively one-eighth to one-fourth inch shorter than the ulnar, which lessens ulnar flexion there. At the elbow the carrying angle is increased. Usually the hand does not deviate, though the ulnar head is more prominent. Prevention is by removing only the head, keeping extraperiosteally and capping the neck over with fascia.

A dislocated radial head may be shoved back in place by Patterson's maneuver. The joint is strained open by ulnar flexion, extension and supination.

Pronation and Supination

When the range of this motion is becoming limited, it does so in pronation, which is unfortunate, as supination or palm up is

a very useful position and the more difficult to acquire because it is working against gravity If the motion must be frozen slight pronation is preferable, but ability to supinate is most desirable Equal motion takes place at each radio-ulnar joint, so restriction of either joint checks the motion Therefore, removal of the head or a segment of the neck of whichever joint is to blame frees the motion Motion is blocked in dislocation because the two parts of the pivot are apart, and is restored on reduction by again placing them together Synostosis anywhere between radius and ulna effectively obliterates the motion by fusing the bones together, and in malunion of radius and ulna with much angulation the motion is checked.

In paralytic cases where there is some limited degree of supination but not enough, a high rotary osteotomy on the ulna as suggested by Milch will place the range of motion into the midposition from which it can supinate sufficiently Union and correct rotation can be insured by a key bone graft.

In reconstruction such as applying an abdominal skin pedicle to the forearm or hand the forearm may be fixed in an exact degree of supination by transfixing both bones with a Kirschner wire. Similarly, pronation and supination may be controlled on doing an arthrodesis of the wrist without the usual necessity of applying the cast to the axilla, merely terminating it at the elbow (See Fig 157, Chapter 5) For arthrodesis of the wrist it is necessary to embed the Kirschner wire in the plaster cast.

Synostosis Between Radius and Ulna

Cross union may take place between the two bones at either radio-ulnar joint or anywhere along the shafts, usually opposite where the bones have been fractured It

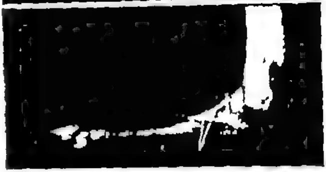


Fig. 504 (*Top*) Case G P Dislocation of head of radius with angulation of ulna at fracture where horse kicked the back of the ulna a year previously

Fig. 505 (*Bottom*) At operation the ulna was straightened, allowing the head of radius to be replaced Through a drill hole in the ulna both a stainless-steel wire and a graft of the palmaris longus tendon were looped about the neck of the radius to hold it in place. The wire held until in a month, when the tendon graft was strong it was then removed.

occurs as bony growth along stripped up periosteum hematoma, or interosseous membrane, especially after severe fractures in which the intervening soft parts were also injured, making a pathway or organized clot between the two bones. If for fracture both bones are operated upon through the same incision, it is best to first undermine the skin so each bone can be approached between different sets of muscles in order that direct communication between the two bones will not be established

Treatment. For synostosis at the bone ends, a segment of the neck of the bone is removed and a tendon graft sling is made to encircle the ulna and flexor ulnaris tendon if at the lower end, whereas if at the upper end, a tendon graft is looped about the radius and fastened to a drillhole in the ulna

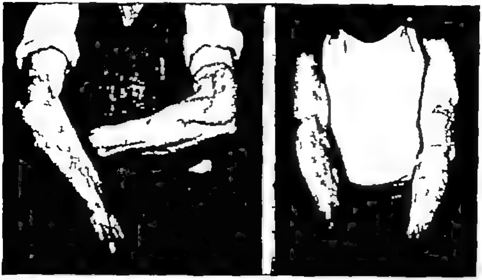


FIG. 506 Case T A. Keloids from burns removed and replaced with half thickness skin grafts.

in order to keep the bones from diverging.

If the synostosis is at the lower part of the forearm a segment of the ulna just above it can be removed, and if at the upper end the same can be done to the radius.

Synostoses along the shafts should be excised very thoroughly because there is strong tendency to recurrence. Entering between ulna and extensor ulnaris muscle the soft parts, together with their nerve supply, are reflected off from the back of the bones and interosseous membrane, preserving the artery which perforates it if possible. Part of each bone as well as the synostosis and interosseous ridges are excised, and good muscle is sutured across the gap to separate them A fascia lata covering of the bone may occasionally be needed

FIG. 507 Case W R. W

(*Top*) Keloid from a burn from exploding gasoline.

(*Bottom*) Same after excision and thin skin grafting

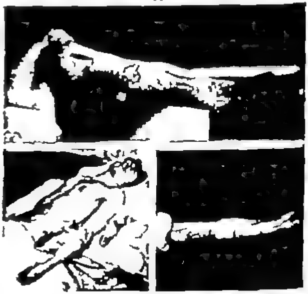


FIG. 508 Case A. C.

(A) Arm was caught between two rollers, resulting in sloughing in antecubital space, injuring the median nerve.

(B) Tubular pedicle in transit.

(C) Pedicle in place. Scars excised.

if the surroundings are very cicatricial One bone may be covered by special cellophane (See page 392) If one is radical and thorough at least half range of motion can be expected

Nonunion

Nonunion of forearm bones is common, especially at the lower end of the ulna Incomplete immobilization is usually the cause, but often infection plays a part. A

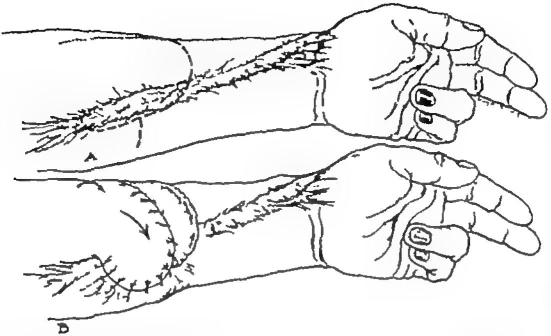


Fig. 509 Breaking a line of tension. The scar is partially excised and cut across to relieve tension. A flap of skin is swung across the line of pull, a thin skin graft covering the denuded area.

case of nonunion in which the area over the fracture site is broadly cicatricial needs first replacement of soft parts by pedicle skin graft. Following osteomyelitis, bone grafting should not be done until one or two months have elapsed, and then only with the protection of penicillin Even so, there is the gamble that the bacteria may be penicillin resistant. In an old case of nonunion lower than the middle of the forearm where the radius has united but a gap is still to be filled in the ulna, one can produce a synostosis between the lower fragment of the ulna and the radius and so quickly terminate the case. The upper end of the ulna will be long enough to give stability of the forearm, and there will be good pronation and supination.

Malunion

In malunion of radius and ulna the greater the angulation, the less pronation and supination will be possible, as their pivots and the bones which are the axles can turn only when in alignment. Ten weeks are usually required to heal forearm fractures If the cast is removed too early the bones will, from the strong flexors and the force of gravity, angulate at the fracture site into pronation and flexion. Supination is, therefore, checked the most. If only one bone is angulated, it is usually the radius.

Treatment is by open corrective straightening of the bones by osteotomy and bone graft or other fixation, shortening one bone if necessary to give the correct relative lengths of the bones for their participation in the wrist joint. The ulna at the wrist should be a little shorter than the radius.

Operations on Bones of Forearm

The ulna, being subcutaneous throughout

A B C D

FIG. 510 (A and B) Malunion of forearm bones. Severe infection and osteomyelitis wrecked the hand.

(C and D) Preliminary bone straightening has been done, a wedge osteotomy of radius, and an overlap shortening of ulna.

its length, is easy to approach. The neck of the radius can be reached between the anconeus and extensor ulnaris, reflecting the supinator brevis and watching for the posterior interosseous nerve. It can also be reached rather deep in front between the brachioradialis and the pronator teres. The shaft is accessible between the extensors of fingers and wrist and the lower third of the radius between the extensors of the thumb and the brachioradialis, avoiding the radial nerve.

FIG. 511 Case P G

(*Top*) Forearm caught in a revolving shaft destroying structures on dorsum and resulting in nonunion of the fractured radius and ulna.

(*Bottom*) It was necessary for only the radius to unite because fortunately there was a low synostosis. The forearm was then stable and had good pronation and supination. The lower fragment of the ulna became porotic from disuse.

The wrist was arthrodesed to have ten dons available to transfer to extend the digits. This was done with good result.

To place bone ends together without strain and with less chance of displacement, muscle pull should be considered. The cross muscles are supinator longus, pronator teres, extensors of the thumb, and pronator quadratus. These have pronatory and supinatory effects and draw the bones together In radial fractures above the pronator teres, the supinator brevis supinates the upper fragment, but below the pronator teres the pronator neutralizes this. Therefore, fractures above the latter should be put up in supination and those below it in the midposition. In all forearm fractures the flexors tend to flex and pronate the lower fragment. If low fractures are put up in pronation, the extensors of the thumb, which are supinators, will be tightened, displacing the upper end of the lower fragment forward. This is corrected by using the midposition. Full supination also displaces here, drawing the bones together by the pull of the pronator quadratus.

The use of anvil and osteotome facilitates separating and shaping the bone ends, and a small handy with saws is useful. Often there will be a strain in bringing the ends of one of the bones together because of inequality of length. It is the interosseous membrane that makes it impossible to displace the bone longitudinally Instead

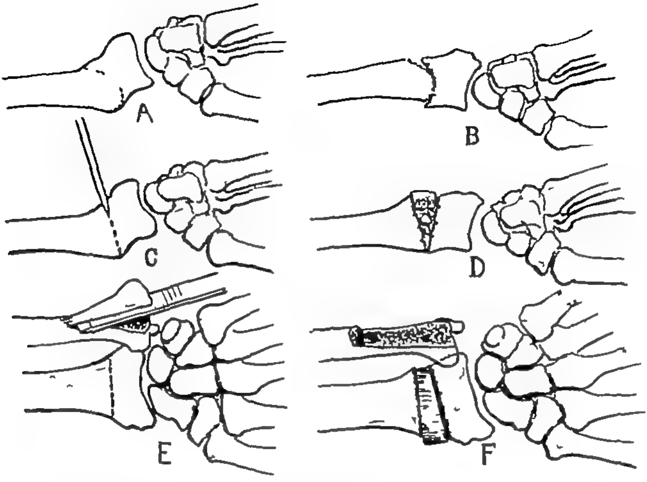


FIG. 512 Operations for malunion of Colles's fracture.
(A and B) Osteotomy along the curve indicated gives angulation volarward and the desired lengthening of the radius.
(C, D E, and F) Campbell's operation utilizing part of the prominent ulnar head for a double-wedged bone graft to furnish angulation and elongation of the radius.

the other bone must be shortened to suit, or the gap bridged by bone graft.

Often the head of the ulna projects too far in the wrist because of shortening of the radius from absorption, overlapping, or angulation. This tips the hand radialward and interferes with anteroposterior, lateral, and pronatory motions of the wrist The head of the ulna should be excised leaving the styloid in place The ulna may be shortened. The ulna cannot be shortened above and drawn upward, as above stated The shortening must be done near its lower end by a long oblique or jogged osteotomy Approximation and fixation should be firm as nonunion here is frequent.

Secondary operations on forearm bones are so often followed by nonunion that grafting is generally resorted to, especially after nonunion. The bones are too small for sliding grafts, the choice being firm onlay grafts from the tibia and stainless steel screws. Good workmanship gives good union.

A gap in one bone may be filled with a bone graft preferably from the fibula, stepping it at each end and screwing it in place. A segment of ilium may be used, pinning it in place as we do with metacarpals. If the defect is small, the other bone may be shortened Pronation and supination should be considered, remembering that the ulna does not turn but that the radius does The ulna is the essential bone at the elbow for stability, and the radius is similarly essential at the wrist. A gap high in the radius

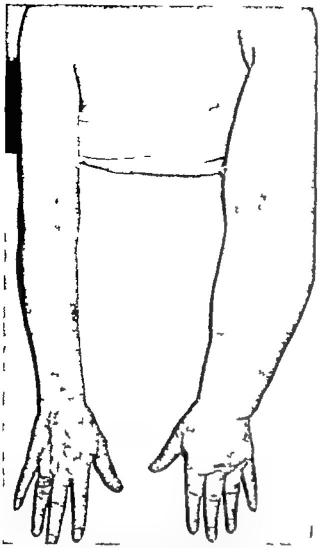


FIG. 513 (A) Lymphedema following radical mastectomy four years previously, causing distress from its great weight and having frequent flare ups of infection in the lymph channels. Skin and water logged subcutaneous fat and fibrous tissue were removed en masse down to the deep fascia from the length of the dependent or larger half of the arm. Split skin grafts were taken from this skin and applied under pressure over the deep fascia.

or low in the ulna is not too crippling, and a low synostosis is a shortcut when the gap is in the lower half of the ulna.

For absence of the lower end of the radius the upper shaft of the fibula together with its head was grafted (Boyd) The head furnished a good socket for the carpus and there was considerable motion after two years. Similarly a fibula graft into the radius may be arthrodesed into the carpus removing the ulnar head for freedom of pronation and supination A simple fixation is to place subcutaneously in the palm a Steinmann pin through the carpus, graft and radius.

MALUNITED COLLES'S FRACTURE

It is sometimes surprising to hear a person with great deformity from an old Colles's fracture claim that it does not disable him, though he states it did for a long time. From malunion the muscle balance of the hand is upset. The tendons at the wrist pull around corners and at wrong angles of approach. The head of the ulna projects into the wrist, limiting motion, and the hand deviates radialward. Though arthritis may have resulted, much of the disability can be relieved by operative correction

Rixford's Operation. Through an incision on the radial side between extensors of the thumb and brachioradialis protecting the radial nerve, a curved osteotomy is done straight across the radius. This is made starting at the dorsal surface with a gentle curvature which is gradually increased until the volar surface is reached. When the distal fragment is then drawn down around the curve and into place, the effect will be both a correction of angulation and of length

Campbell's Operation. Through the above exposure the radius is severed straight across at the fracture line. The lower end of the ulna is uncovered and with an osteotome the outer posterior half is chiseled off from below upward as a long wedge, as the breadth of the radius Its rounded surface is chiseled flat so as to wedge it in two dimensions. The radial fragments are pried apart, angulating the distal one, inserting the wedge so that there will be both angulatory correction and lengthening of the radius. The prominence of the ulna will also be eliminated The styloid process and triangular ligament are replaced by suture.

In a badly malunited Colles's fracture, it [illegible] ageous to hold the fragments [illegible] h a bone graft such as a strip

FIG. 513 Case C. R. (B *Left*) Skin graft which did cover half the circumference has shrunken to only one-third the circumference.
(C, *Right*) One year later Size of arm is greatly reduced. Second half of edematous tissue has not yet been removed.

from the ulna. The ulnar head usually projects against the carpus in these cases interfering with wrist motions and with pronation and supination. For this and other conditions such as painful arthritis of the radioulnar joint, the head of the ulna should be removed If removed above the pronator quadratus, or if this muscle is weak, the ulna will be unstable on the radius and it will be necessary to place around it and the flexor ulnaris tendon a tendon sling.

LYMPHEDEMA OF UPPER EXTREMITY

Following a radical mastectomy or infection of filaria there may be in a few years extreme lymphedema of the whole limb, especially of the under portion of the upper arm and forearm and the dorsum of the hand. Early edema will go if lymph drainage is established by a pedicle skin flap, but after it exists long it becomes organized with firm, thick fibrosis. It is then so irreversible as to need excision The arm feels very heavy and there will be periodical flare-ups of infection spreading widely in the dilated lymph channels necessitating chemotherapy The Kondoleon operation does not help

The thickened tissue external to the deep fascia must be excised and the arm covered by skin grafts. Much free lymph is found riding the deep fascia. The split grafts are first removed from half the arm by the dermatome. Then the skin and massive

subcutaneous tissue is removed from the dependent or larger half of the arm. An Ace bandage is wound the length of the limb to check hemorrhage, and as it is unwound from the hand upwards, the vessels are caught. The skin graft is then sutured in place and a pressure dressing applied. This method which we have used is rather bloody At a second operation the remaining edematous tissue is similarly removed It will be found by then that the first skin graft will have shrunken to a strip only one-third of the circumference in width.

Molem found in operating mostly on legs that his grafts took better if he applied them to granulations a week or so after removing the edematous tissue. Macey slit the length of the limb, peeling back the edematous tissue on each side from the deep fascia until half the circumference of the limb was denuded. After covering this with skin grafts, the skin and fat were sutured over the skin grafts. This made an excellent dressing for the skin grafts even though some hematoma formed outside of the grafts. In ten days the redundant tissue was trimmed away suturing the remaining borders of the skin graft The tourniquet was kept in place until the pressure dressings were applied. The remaining edematous tissue is removed in a third operation

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PART THREE

INJURIES AND INFECTIONS OF THE HAND

12

Injuries of the Hand

OPEN WOUNDS

General Treatment

Living things have always been subject to trauma, but the present period of modern world warfare might be called, for the human species, the age of trauma. Wounds have always accompanied the struggle for existence of all forms of life, from their inception to the present time. Through the ages both plants and animals, of necessity, have evolved methods of healing every tissue and all types of wounds. Repair of bones started with the bony fishes which were the first creatures to have them, and already in the bones of prehistoric reptiles fracture healing is seen to be like our own. From this long heritage each of our tissues has established a method of healing, evolved and found good throughout the ages. We need but to think how bones, tendons, fascia, and nerves rejoin, and how skin recovers denuded areas, intestines heal, and arthritis splints itself, and how even a rupture of the thoracic duct is provided for by hypertrophy of its anastomotic network.

An injured animal licks the wound clean and because of pain lies down and holds the injured part still. Nature arranges for the hyperemia of repair, muscle spasm for splinting, leukocytosis and production of antibodies for sterilization, the pointing and discharging of abscesses, and the final healing.

The surgeon should build upon these fundamentals rather than on some marvelous healing salve of recent publication. In many ways we can aid enormously in this battle against infection and in the repair.

1. First we can attend to the wound, at once ridding it of the contamination before it becomes infected.

2. We can refrain from making the condition worse, such as by introducing and spreading new infection or mechanically or chemically adding more trauma to the tissue.

3. We should cleanse the surrounding skin of hair, dirt, and bacteria.

4. We should excise the whole surface of the wound, extracting any foreign body, thus mechanically and completely removing the layer of germ filled, traumatized tissue which would be destined to go through infection and sloughing.

5. All exposed vulnerable structures—such as tendons, nerves, joints, and bones—should be closed over, and the wound as a whole should be closed.

By the above procedures we aid by obtaining an untraumatized, clean surgical wound which heals per primam without the burden of fighting infection and throwing off the necrotic and sick tissue, so necessary before the process of healing.

Circulation, rest, and time aid healing.

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Circulation, rest, and time aid healing

The first is accomplished by avoiding either any ischemia or circulatory congestion. Ischemia comes from too tight suturing, *from joining skin and deep tissues under tension*, or from pressure of too tight dressings or plaster casts not cut or spread when the limb swells If the limb hangs down, *the congestion spoils healing* *Elevation* relieves the circulation by aiding lymphatic and venous drainage. Most injured limbs should be splinted, and all should be elevated *and given local rest by splinting and* general bodily rest in a hospital. Fractures should be set early, except in open explosive wounds they may be set at the secondary closure. *Digits should not be amputated* if any part of them, bone, tendon or skin, may be of use in the reconstruction. The thumb is so valuable we should preserve all its parts and the maximal length Each of these principles will be more fully discussed

Hands following injury are so prone to stiffen that it is a big problem throughout to keep them limber *This is* done by prompt closure and by keeping the hand moving A wound left open stiffens a hand Edema is prevented by early closure, elevation and continued exercise Edema and immobilization lead to stiffening Only the injured part should be splinted, the rest of the hand remaining free to move The patient must be compelled to move it. Joints allowed to remain in faulty positions will set there This means the flexed position of the wrist, the straight position of the *proximal finger joints and the position of* the thumb at the side. This is the position of nonfunction which injured hands tend to assume and in which position they stiffen *The patient holds his wrist flexed* This automatically tightens the extensor tendons to pull the proximal finger joints into extension and the thumb to the side of the *hand and backwards* *When the proximal* finger joints are extended the intrinsic muscles have lost their angle of approach and so cannot flex them . As the proximal finger *joints extend the long flexors* pull the distal two finger joints into flexion. The hand should always be placed in the position of function and maintained so until well . Our goal should be throughout treatment always to maintain this position. Some splinting is necessary It may be to restrain the movement in one direction only or it may be springy or elastic in type. Proximal finger joints, if kept flexed, will not stiffen If the wrist is kept in dorsiflexion, the muscle balance will be maintained so the hand will have the tendency to assume the position of function instead of that of nonfunction.

Examination

An open wound should be viewed suspiciously lest there be overlooked severance of nerve or tendon ruptured muscle, fracture, or dislocation, foreign body, hematoma, or an opening for contamination of a joint or tendon sheath. Knowing anatomy, simple tests for injured nerves or tendons are only too easy One may overlook a severed flexor sublimis or proprius tendon, but it is inexcusable to miss severance of the other main tendons or the nerves. For *the long flexor or extensor tendons of the* thumb, observe the action of the distal joint, for abductor pollicis longus, the forward position of the thenar eminence, the dropped thumb arch and weakness on pinching for long extensor tendons of fingers the dropped proximal finger joints, for flexor profundi, the loss of flexion in the distal finger joints. Injury of lumbricales or interossei is shown by loss of extension of the distal two finger joints, of lateral finger motion or of flexion of the proximal finger joints and at the same time extension of the distal two

Nerve tests of sensation and of motion of the intrinsic muscles in the hand are covered in Chapters 8 and 10 On finding one lesion always search for others, even at a distance. When false motion, deformity, *or the nature* of injury makes one sus-

picious of fracture, dislocation, or foreign body, lateral and anteroposterior and oblique roentgenograms should be taken

Time Factor Between Accident and Operation

The golden time for primary operative repair is during the fleeting few hours before contamination changes to infection All open wounds are contaminated, but in the interval before the bacteria multiply sufficiently to invade the tissues, by surgically removing infected and traumatized tissue from the wound we can often perform a primary repair of the damaged tissue, as in a clean surgical wound If primary repair is not possible then, we may at least primarily close the wound to outside infection and do a secondary repair later

A patient with an open wound involving deep structures should, therefore, have the wound covered with sterile gauze and be rushed to a hospital. Six hours is the orthodox time limit. If, however, we are too rule-bound, we will overlook opportunities of closing favorable wounds. Wounds are so variable in degree of tissue damage, permeation with foreign bodies, amount of infection, and special virulence of the bacteria, that the time limit is also a matter of degree.

A working rule is necessary in institutional work and on the average makes for good results, but if the various factors for success or failure in each individual case are weighed and judged wisely some cases will be refused for operation within the six hour time and others can be operated upon up to 24 hours If the wound is by crushing and is dirt-ground, closure even early is unwise, and also if from a human bite or contaminated from a virulent human infection In a crushed or torn wound repair of the deeper structures may be dangerous. A cleanly incised wound with minimal tissue damage or contamination can be fairly safely closed even late Thus, by carefully selecting the case, and when a smear from the wound does not show cocci or an excess of leukocytes, primary operative repair with closure has frequently been successful up to 12 hours and even 24 hours Beyond this extreme limit the chances are in favor of very bad infections

In healthy individuals wounds often heal primarily without any demonstrable multiplication of bacteria. The six hour limit was based on experiments entailing gross contamination, smearing dirt in the thighs of guinea pigs and clinically on war wounds, and on hospital statistics of wounds of all sorts, and repair in different ways. Böhler in his excellent clinic adopted a six and eight hour limit for closure of open fractures. The six hour rule was satisfactory for war wounds from missiles.

There are still other factors that argue for flexibility in this time limit, namely, the resistance and health of the patient, and the quality of the operation and after treatment as regards the factors discussed in this chapter Thus, by considering all factors including management, primary operation can be successfully done after six hours in a gradually decreasing number of cases, but never after 24 hours Operation on late infected cases scatters billions of germs through the tissues, flaring up infection to catastrophe.

The above was written before the advent of penicillin and without this drug it still holds Penicillin should be started at once, locally and parenterally It extends the time between accident and débridement though this should always be kept as short as possible. The first surgery done still determines the fate of the case

Anesthesia

Some form of anesthesia is essential Fortunately, local anesthesia about clean fresh wounds is safe, though in a *digit* adrenalin must be omitted for fear of

The first is accomplished by avoiding either any ischemia or circulatory congestion Ischemia comes from too tight suturing, from joining skin and deep tissues under tension, or from pressure of too tight dressings or plaster casts not cut or spread when the limb swells. If the limb hangs down, the congestion spoils healing Elevation relieves the circulation by aiding lymphatic and venous drainage. Most injured limbs should be splinted, and all should be elevated and given local rest by splinting and general bodily rest in a hospital. Fractures should be set early, except in open explosive wounds they may be set at the secondary closure Digits should not be amputated if any part of them, bone, tendon or skin, may be of use in the reconstruction. The thumb is so valuable we should preserve all its parts and the maximal length Each of these principles will be more fully discussed.

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Examination

An open wound should be viewed suspiciously lest there be overlooked severance of nerve or tendon, ruptured muscle, fracture, or dislocation, foreign body, hematoma, or an opening for contamination of a joint or tendon sheath. Knowing anatomy, simple tests for injured nerves or tendons are only too easy One may overlook a severed flexor sublimis or proprius tendon, but it is inexcusable to miss severance of the other main tendons or the nerves. For the long flexor or extensor tendons of the thumb, observe the action of the distal joint, for abductor pollicis longus, the forward position of the thenar eminence, the dropped thumb arch and weakness on pinching, for long extensor tendons of fingers, the dropped proximal finger joints, for flexor profundi, the loss of flexion in the distal finger joints Injury of lumbricales or interossei is shown by loss of extension of the distal two finger joints, of lateral finger motion or of flexion of the proximal finger joints and at the same time extension of the distal two

Nerve tests of sensation and of motion of the intrinsic muscles in the hand are covered in Chapters 8 and 10 On finding one lesion always search for others, even at a distance. When false motion, deformity, or the nature of injury makes one sus

picious of fracture, dislocation, or foreign body, lateral and anteroposterior and oblique roentgenograms should be taken

Time Factor Between Accident and Operation

The golden time for primary operative repair is during the fleeting few hours before contamination changes to infection. All open wounds are contaminated, but in the interval before the bacteria multiply sufficiently to invade the tissues, by surgically removing infected and traumatized tissue from the wound we can often perform a primary repair of the damaged tissue, as in a clean surgical wound. If primary repair is not possible then, we may at least primarily close the wound to outside infection and do a secondary repair later

A patient with an open wound involving deep structures should, therefore, have the wound covered with sterile gauze and be rushed to a hospital. Six hours is the orthodox time limit. If, however, we are too rule bound, we will overlook opportunities of closing favorable wounds. Wounds are so variable in degree of tissue damage, permeation with foreign bodies, amount of infection and special virulence of the bacteria that the time limit is also a matter of degree

A working rule is necessary in institutional work and on the average makes for good results, but if the various factors for success or failure in each individual case are weighed and judged wisely some cases will be refused for operation within the six hour time and others can be operated upon up to 24 hours. If the wound is by crushing and is dirt-ground, closure even early is unwise, and also if from a human bite or contaminated from a virulent human infection. In a crushed or torn wound repair of the deeper structures may be dangerous. A cleanly incised wound with minimal tissue damage or contamination can be fairly safely closed even late. Thus, by carefully selecting the case, and when a smear from the wound does not show cocci or an excess of leukocytes, primary operative repair with closure has frequently been successful up to 12 hours and even 24 hours. Beyond this extreme limit the chances are in favor of very bad infections.

In healthy individuals wounds often heal primarily without any demonstrable multiplication of bacteria. The six hour limit was based on experiments entailing gross contamination, smearing dirt in the thighs of guinea pigs and clinically on war wounds, and on hospital statistics of wounds of all sorts, and repair in different ways. Böhler in his excellent clinic adopted a six and eight hour limit for closure of open fractures. The six hour rule was satisfactory for war wounds from missiles.

There are still other factors that argue for flexibility in this time limit, namely, the resistance and health of the patient, and the quality of the operation and after treatment as regards the factors discussed in this chapter. Thus, by considering all factors including management, primary operation can be successfully done after six hours in a gradually decreasing number of cases, but never after 24 hours. Operation on late infected cases scatters billions of germs through the tissues, flaring up infection to catastrophe.

The above was written before the advent of penicillin and without this drug it still holds. Penicillin should be started at once, locally and parenterally. It extends the time between accident and débridement though this should always be kept as short as possible. The first surgery done still determines the fate of the case

Anesthesia

Some form of anesthesia is essential. Fortunately, local anesthesia about clean fresh wounds is safe, though in a digit adrenalin must be omitted for fear of

The first is accomplished by avoiding either any ischemia or circulatory congestion Ischemia comes from too tight suturing, from joining skin and deep tissues under tension, or from pressure of too tight dressings or plaster casts not cut or spread when the limb swells. If the limb hangs down, the congestion spoils healing Elevation relieves the circulation by aiding lymphatic and venous drainage. Most injured limbs should be splinted, and all should be elevated and given local rest by splinting and general bodily rest in a hospital. Fractures should be set early, except in open explosive wounds they may be set at the secondary closure Digits should not be amputated if any part of them, bone, tendon or skin, may be of use in the reconstruction The thumb is so valuable we should preserve all its parts and the maximal length. Each of these principles will be more fully discussed

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necrosis, and instead a catheter is placed about the base of the finger to retain the anesthetic. An ultrafine, flexible No 30 needle, which is almost painless, is introduced through the thin skin at side or dorsum in a finger instead of through the tough, tender, volar skin. Too tight infiltration lessens local resistance.

In larger wounds block anesthesia (p 97) is used, and for more extensive ones brachial plexus block. Under one of the many forms of general anesthesia the surgeon can work more extensively and with greater ease. The regional anesthetics are given after the tourniquet is placed. Ischemia from tourniquet is indispensable for proper débridement in the hand. After wrapping the limb in a towel an Esmarch bandage winds out the blood until the blood pressure band on the upper arm is pumped to 300 mm of mercury (p 95). For a digit a catheter will suffice.

Cleansing Skin

While holding sterile gauze against the wound the surrounding skin is shaved and thoroughly cleaned widely, using benzine and much soap and water and mechanically rubbing with gauze to as far as the edges of the wound. After the usual painting of the skin as an additional safety measure with an antiseptic such as alcoholic merthiolate solution, and placing the sterile drapes, regular operating room asepsis is maintained using cap, mask, gown, fresh gloves etc.

Débridement or Excision of Wound

Before us is now a dry wound lined by traumatized tissue ranging from dead to sick and contaminated with bacteria. Our object is to convert it into a clean surgical wound. Washing a wound with a large amount of normal salt solution or sterilizing it with an antiseptic does not constitute débridement as it does not remove from the wound the surface tissues which have been traumatized and cannot remove all the bacteria. Every crumb of unclean traumatized tissue must be excised or it may cause infection. Débridement in the sixteenth century meant enlargement of the wound or unbridling, but it now means complete excision.

There are two different methods of cleansing and débriding the wound, but as either method has been found to give good results the issue between them may not be of great importance. One procedure long used in the Massachusetts General Hospital in Boston is to flood the wound in all its interstices with ten gallons of normal salt solution. To avoid a deluge Marble places the limb over a flat, screened pan from which a pipe leads to the waste. The excision is done as the surface tissue floats up in the solution, the traumatized tissue being identified by its appearance.

The other method is first to sop the wound in all its interstices with a half-strength tincture of iodine as used on skin and then to blot it dry at once to limit its action on the surface. This destroys surface bacteria and so marks the tissue that every particle can be excised. With toothed forceps and sharp plastic scissors (curved, flat, and double-pointed) the complete surface of the wound is systematically excised for 1 or 2 mm. deep, or more if necessary to remove all nonviable tissue. First, the complete skin margin is excised, and circling deeper and deeper in the wound all is excised so completely in a dry and bloodless field that not a crumb of marked tissue remains. Exposed nerves, tendons, articular surfaces, or essential structures are spared. The tendon and nerve ends are thinly clipped off and ends of fractured bones are chiseled off to good bone. On completion we have a clean surgical wound lined with viable tissue free from bacteria, traumatized tissue, and chemical.

The latter method unquestionably insures more exact and complete excision. After it is done the wound may for addi-

tional safety be flooded with normal salt solution without the danger, as in the former method, of expressing contamination into the deep layers and interstices of the wound Vitality of tissue should not be weakened by chemicals, but that does not apply to the outer cornified layer of skin or to tissue that is excised Emotional fleeing from chemicals as one's pet abomination may be superfluous, as both methods succeed when carried out properly

Early excision of the wound is the best prophylaxis for infection, including tetanus and gas Clostridium infections, and is more important than prophylaxis by sulfonamides or penicillin though these should be used.

Débrided or Surgically Clean Wounds

Our best method is not perfect. Beyond what has been excised, the tissues may be partially damaged and some germs may have escaped us Tissue, however, is vital, and has some margin of safety We know that in an operating room 20 air borne germs will land in a Petri dish every half hour, and still our operative wounds heal well. Primary healing is more or less tolerant or dependent on the quantity or virulence of the germ Foreign bodies or tabs of necrosis may determine infection Large catgut knots or buried catgut sutures act similarly If we excise dead tissue we should omit placing dead catgut. In a wound any buried suture or ligature beneath the skin may determine infection As a rule none should be left in. Some are necessary to stop bleeders, close dead spaces, and join structures They should be minimized and of a material that will do the least harm. Most bleeding stops soon on sponge pressure and can be controlled by pressure of dressings Persistent bleeders may be tied with No 000 or 00000 catgut or hair like No 38 stainless steel wire Such fine catgut is soon gone, and even granulating wounds heal over the wire. If there is extensive oozing, a tiny rubber drain may be placed away from vulnerable parts for 24 hours

Injured deep structures can now be reconstructed in favorable cases of prompt operation and with tissues not too badly torn, dirt ground, exploded, or otherwise traumatized Foreign body suture material should be reduced to a minimum Catgut is worse than silk, but silk is bad enough Removable stainless steel wire is the best. The slender strand is reactionless in the tissues, can be used to hold fascia, ligament, tendon, bones, or other structures together and to close dead spaces, and can be removed from the outside as soon as the tissues have united, leaving the inside permanently free from any foreign body

Examples of how to use the stainless steel wire are shown in the illustrations Many more methods based on this principle can be devised by the surgeon as needed Never yet have I seen infection led into the tissues by these wires if not placed in moist creases In removing, they are iodized, cut beneath the surface by drawing them out a little and then removed by pulling on the other strand if they are in loop form, or by a pull-out wire if placed double as in tendon suture. Fractured ends of phalanges or metacarpals can be fastened together by No 35 or 34 stainless steel wire through drill holes and, being then free from movement, may be left permanently Fascial edges may be closed with a running stitch, bringing each end of the wire out through the skin and fastening it with a shot, but usually by merely catching the fascia in the wire skin suture used as a figure-of-eight. The two ends of a wire holding ligament or other deep structure together may be brought out through the skin and tied over a tiny bolster Dead spaces are either encircled or their walls are by loops broadly drawn together from opposite directions by slender No 35 or 34 wire, which is brought out through the skin at a distance and there fastened over buttons or bolsters just taut enough to obliter

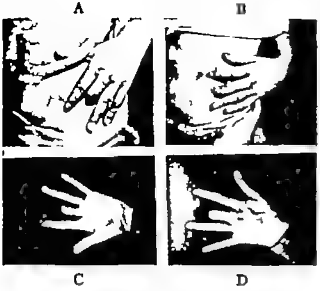

FIG. 514 Case A. B Avulsion of skin from long finger as his ring caught on a nail when he fell off a fence.
(A) The distal portion of the finger was amputated as it had no blood supply but the remainder was Thiersch-grafted until a tubular pedicle could be applied (B) Pedicle attached. (C and D) Result.

ate the space. Such sutures do not interfere with healing There is no tissue reaction around them.

If one is at all dubious about obtaining primary union, it is better to omit reconstructing the deep parts and be content for the present with merely closing the skin, postponing the deep reconstruction.

Nerves even to as far distal as the distal crease in a digit may be accurately sutured at that time by the finest silk, catching just the sheath if the surgeon has by preparation equipped himself for this type of work. It is a better rule, however, merely to fasten the nerve ends together by one fine stainless steel wire to prevent retraction and routinely to perform a secondary nerve suture later under ideal surgical conditions. Such a late repair gives better regeneration than after primary nerve suture as it is usually done. Primary tendon repair is discussed below

The laceration often needs enlargement for better access or for retrieving foreign bodies or retracted nerves or tendons. Unfortunately, it is too prevalent to make this incision thoughtlessly, blasting principles of plastic surgery A transverse laceration should not be enlarged by cutting up from its center, thus making a T Instead, an incision may be made upward from one of the ends of the laceration and another made downward from the other end This gives excellent exposure by the two flaps and leaves a less objectionable bayonet shaped scar The enlarging incision should not cross flexion creases at a right angle or be median longitudinal It is always possible in crossing joints to curve around in a zigzag way and so avoid ugly keloid formation To retrieve a tendon end, a new short, transverse incision that later becomes invisible will often suffice.

Refrain from Making Wound Worse

Many wounds are made worse by meddlesome surgery Assuming that the wound has escaped popular remedies such as tobacco juice, cow dung and cobwebs, it still may be infected by unclean dressings, by fingers, or instruments used in the emergency to stop hemorrhage. A fresh wound is as susceptible to infection as is an operative wound and so demands similar precautions, including the face mask. Talking over a wound contaminates it by spray with human acclimated germs. These are usually worse than those incurred in the injury and are present also on fingers or whatever we touch. Even though a wound has been contaminated from the outside we are not justified in carelessly adding these virulent germs to it. Wounds are especially susceptive to outside contamination in the first five days. It usually falls to the lot of the young surgeon to care for the hand wound, and he should learn early that any rough handling of the tissues or unnecessary surgery adds to the trauma already present. The fact that the tissues have been wounded, instead of justifying additional surgical trauma, demands all the more that the surgeon have respect for the tissues and handle them tenderly with atraumatic technic.

At this time the injury and the prospects should be evaluated with relation to the patient, and a plan should be determined on for the reconstruction of the hand. Parts may be saved for later use, and hopeless parts removed. Immediate cover may be applied. At this time digits may be so placed that they will work against each other for prehension. Nerves also should be sutured, or joined temporarily with one stainless steel wire so that eventually sensation and motion will return.

Cover All Vulnerable Parts and Close Wound

Tendons, nerves, joints, and bones cannot be left exposed to the outside world and when infected cause sloughing, purulent arthritis, osteomyelitis, months of dressing, and final crippling. Many of us have seen the fate of the patient with the mangled limb determined by the first dressing, consisting merely of placing the limb in a fracture box and treating with compresses. In contrast to this, all vulnerable parts should be protected from such a fate by covering them over and the wound closed, thus saving months of invalidism, compensation and industrial waste, and big permanent disability.

These parts, being avascular, will not take a skin graft. Therefore, we should cover them at once by plastic pedicle flaps of skin from the immediate neighborhood and close in the areas so denuded by split skin grafts. The latter should not be over .012 inch in thickness if the limb in general has been traumatized, but otherwise can be as thick as .020 inch. The flap should be broad and massive, long enough to cover easily the vulnerable parts, and should have its pedicle proximal.

If from loss of skin the wound cannot be closed without tension, the same procedure should be resorted to, using either a pedicle flap or making an incision parallel to the wound, undermining a broad ribbon of skin between and drawing it over to close the wound. The newly denuded areas should

Fig. 515. In an automobile accident most of the back of the hand was ground off including tendons. The wrist joint was wide open. The wound was excised and closed primarily. Skin flaps from side of hand and thumb were made to cover the wrist joint and thin free graft was used to cover in the remainder.

The dorsum was later covered by good pedicled skin and a new set of extensor tendons from the foot and a layer of paratenon fat from over the triceps tendon was placed between them and the bone.

An excellent hand was obtained with full motion and flexibility.

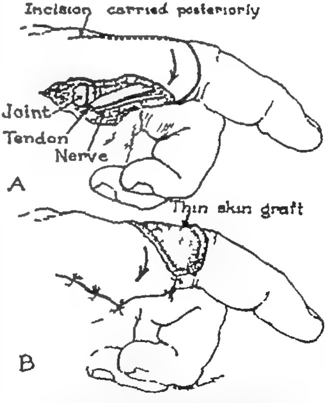

Fig. 516. Primary treatment of open wounds. After thoroughly débriding and cleansing all exposed vulnerable tissues such as nerves, tendons, bones, and joints are closed over with a primary plastic skin closure. In this case a flap of skin is swung from the dorsum of the finger to cover the vulnerable tissues. A split skin graft is used to cover the denudation left by swinging the skin flap.

be split grafted By some method all wounds made clean enough should be closed.

At times a finger needs amputating and there is a wound of the hand to close. One can fillet the finger and preserve its good skin to cover the defect in the hand. Similarly, by excising a too badly damaged or a fingerless metacarpal enough skin can be gained to cover the defect. If the skin has

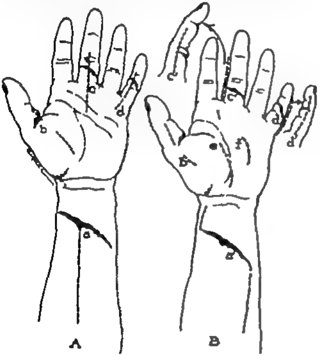

Fig. 517 (A) Incorrect incisions for obtaining exposure in treating lacerations as they cause flexion contractures and T scars.
(B) Correct incisions for the same which are not harmful.

been stripped from a finger, or the skin of the whole hand like a glove has been avulsed, this skin should be thoroughly cleansed, all of the subcutaneous fat should be cut away as in the full thickness graft, and it should be replaced, a few perforations being made for drainage, followed by splinting and pressure. If, however, this skin is not available, the denuded finger or hand can be at once covered by a free skin graft by the dermatome 012 inch in thickness. Meantime, a pedicle can be prepared for later replacing the split graft.

Before penicillin was available there was great danger from infection if we applied an abdominal pedicle to a freshly injured hand The abdominal fat was too susceptible to infection With penicillin, the abdominal pedicle can be used. From small to very extensive denudations of a hand after débridement may be covered by an immediate broad pedicle graft from the abdomen. All should, of course, be closed aseptically Pocket grafts are objectionable as they are so septic. Hands thus closed at once remain remarkably limber and all the vulnerable structures are covered over This is the method of choice where skillful operative facilities are available. It should not be done for wounds from explosives or those that are too traumatized and dirt ground.

Applying Dressing

The wounds after closing are covered with gauze and gauze is packed lightly, not tightly, between the fingers. Fractures are laid in position without splinting at this time by placing the hand in the position of function. The whole hand is then covered by fluff gauze or cotton waste and wrapped snugly with an Ace of flannelette bandage. A slab of plaster may be laid on the volar aspect outside of the dressings This dressing affords pressure to keep down edema and immobility for the fractures and damaged parts. The hand is kept elevated At the next dressing, when the swelling will have gone, the fractures are set, the wounds closed if necessary, and a half or bivalve cast may be applied. Eliminating edema by pressure is to remove a major cause of stiffness as edema plus immobility results in a congealed hand

Badly Traumatized Wounds

Wounds from explosives, or those too badly traumatized or dirt ground for primary closure, should be débrided, loosely packed open, treated with penicillin and closed secondarily in about eight days They should be kept open by fine meshed gauze, nylon or rayon (vaseline being unnecessary if the mesh is fine) Chemotherapy is started at once. The hand is wrapped in a

voluminous pressure dressing, kept elevated and undisturbed On the sixth to tenth day the dressings are removed aseptically in the surgery If clean in appearance, the wound is closed by drawing the skin together, undermining and sliding the skin together or by skin grafting If not clean, the wound is compressed for a few days before the closure is made At the débridement a few sutures of stainless steel wire may be placed encircling the depth of the wound, but not tied At the secondary closure the wound is merely pulled closed by the wires and these are tied

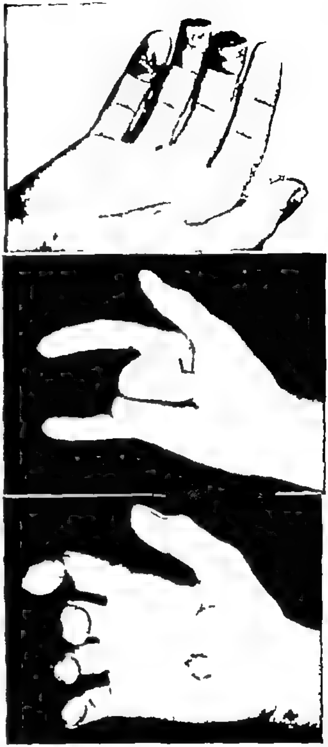

Fig. 518 Immediate palmar flaps to ends of amputated fingers (Courtesy of L. D Howard Lt Col., M C Wakeman General Hospital.)

Chemotherapy

Sulfonamides lightly sprinkled in a fresh wound have been shown to be very limited in value Orally they are of value especially against the bacteria that are penicillin resistant Streptomycin is much stronger Locally penicillin instilled by tubes or its calcium salt diluted 5 000 units per gram with sulfanilamide and insufflated into the wound as a powder are of advantage Both sulfadiazine and penicillin should be given systemically for wounds subject to the danger of infection There may be a flare-up of infection if these are discontinued too early Wounds traumatized and dirt ground or from explosives if débrided and kept open, may on the eighth day by the help of penicillin be ready for secondary closure Chemotherapy is developing so rapidly that what is written now may soon be passé.

Circulation

Throughout surgery and especially in reconstructive work, the danger of ischemia should be uppermost in mind Limbs swell after injury or operation, so, though the circulation at the time may seem sufficient, the next day from tightness or slowed circulation there may be thrombosis or necrosis. We should *allow for swelling, leaving* each part with such good vascularity that it will live, and in placing dressings an exact degree of pressure of the bandage is essential, to prevent hematoma on the one hand and not to compress circulation on the other Bandaging, if left to careless *ignorant persons, wrecks* limbs, either in part or in whole, or by causing Volkmann s ischemia. Before closing a wound the tourniquet should be removed and the cir

Fig. 519 (A, *Top*) Explosive wound in palm covered by a fillet from the ring finger in palm and a tubular pedicle for the thumb cleft.
(B *Bottom left*) Bed under tube pedicle is skin grafted.
(C, *Bottom right*) Hand is salvaged. (Courtesy of W B Macomber Lt. Col., M C., Dibble General Hospital.)

culation tested, especially of skin flaps or wherever there is tightness A streak of white skin from a suture, if the tension is not relieved, will be a black streak soon The very tip of a pedicle flap should bleed and the skin should be pink If white or port wine red, next day it will be blistered, thrombotic, or black. Extra time spent at operation correcting tension, angulated or too ambitious pedicles or other circula tory deficiencies well repays To be safe plaster casts should be of only three quarter circumference or bivalved, with wax paper between

Prevention of Tetanus

The incidence of tetanus in this country compared with damp and heavily fertilized ones is low The germ does not grow in normal tissue, but needs preparation of the tissue by bacteria or trauma and must be deep away from oxygen Presence of necrotic tissue and foreign body favor teta nus in contrast to débridement, which is prophylactic. Tetanus is not probable in simple wounds, though it may follow even a scratch. If explosive, such as war wounds, or barnyard soiled, the danger is great. It is scarcely practical to give A.T.S for every trivial wound, and there have been complications from the serum. The ad ministration is advisable, however, in all wounds which are favorable to tetanus It is especially advisable for all war wounds It protects both patient and surgeon After the skin-sensitivity test, 1,500 units are given hypodermically The immunity is short lived, often only a week, a repetition of the dose being necessary on subsequent operation. Active immunization from tox oid lasts for years, or may be permanent. The serum may be omitted only if it is definitely known that the patient has had adequate immunization by the toxoid course as in the military, but in that case it is recommended by the United States Army to give subcutaneously a booster or stimu lating dose of 1 cc. of toxoid In doubtfully adequate immunization, the serum is given and a course of toxoid is started, giving three subcutaneous injections of 1 cc. each at intervals of three weeks

Postoperative Care

In the first 24 hours moderate pressure, preferably with sponge rubber, checks in ternal oozing of lymph and accumulation of hematoma If the area is so large or of tissue so traumatized that oozing is likely, the stitches should be placed far apart to allow drainage between, or small rubber tube drains (3 mm in diameter) are left for the first 24 hours If these remain long they cause infection Air dressings, being dry, are especially free from infection and can often be started after the first 24 hours of compression, using wire frames, boxes, or Cramer wire

Postoperatively, if the limb hangs down, there is congestion, cyanosis, thrombosis, oozing, and from swelling excessive tight ness of skin and surrounding dressings. All postoperative limbs should, therefore, be kept elevated with hand higher than arm, on pillows or splints in bed, or, if ambula tory, on an airplane splint. This drains lymph and venous blood by gravity, easing the circulation Tissue with edema will not heal *Next day without fail* all enclos ing dressings, whether of bandage or plaster of Paris, should be cut through to the skin for the full length and spread if necessary to allow for the swelling If this is not learned by reading, it will soon be mastered by having malpractice suits. All tissues must have circulation to live, and when sick need even more circulation to heal

Rest Local and General

Freshly injured or infected tissue re quires immobility Movement breaks the binding and vascular strands of healing as fast as they form, rendering the tissues boggy with exudate. It prevents healing

and favors infection. The need for splinting is of special importance when there has been extensive tissue damage, where some plastic maneuver or skin graft has been done, or where the vitality of the tissues is in question. Here, splinting turns the tide and allows quiet healing. Immobilization with mild pressure reduces tissue reaction and overhealing Even keloids do not form until the splint is removed. In an emergency one can splint with a molded piece of sheet lead, a wooden applicator or a scroll of wire mesh, a piece of Yucca or a plaster cast. (The standard splints listed in Chapter 4 and plaster of Paris are the most efficient and should be available.)

General rest in a hospital bed conserves the total bodily energy for use in fighting off an infection A few days so spent following the injury are of great benefit.

Late or Infected Wounds

When so much time has elapsed (usually from eight to 24 hours, depending on the type of wound) that germs have multiplied and penetrated into a wound, the opportunity for débridement, repair of deep parts and closure is over, as this would result in dissemination of infection In a clean cut it is still possible that the wound may heal without gross infection, but, if unlikely, wide drainage should be established and necrotic tissue if present should be excised Secondary healing takes twice the time of primary healing, but the open drainage afforded insures safety

A fracture should be set early, placing the traction wire through the pulp of the digit if necessary, and a dislocation should be reduced but other severed deep structures must be let alone. When infection is already present sudden setting of a fracture causes a flare-up, but this may be avoided by setting the fracture gradually by traction. Open fractures should be closed if early, or, if late, treated openly as are other wounds.

Methods of Open Drainage in Late or Infected Wounds In all cases the wound should be laid open and the limb splinted, elevated, kept warm and chemotherapy started. Each of the following methods is useful

1 The wound is lightly packed with fine meshed gauze. Gauze dressing is applied and the limb is enclosed in two-thirds of its circumference by plaster of Paris. It is then let alone for from one to several weeks. Cast should not encircle a freshly traumatized digit. There is much merit to curtain drainage, as in the old B.I.P method, gauze impregnated with liquid paraffin and a small amount of B.I.P mixture (bismuth subnitrate one part, iodoform two parts, and enough liquid paraffin to make a paste) is packed throughout all recesses. It is applied with mild pressure and sealed over with plaster Drainage takes place between the wound and the surface of the packing at the edges, as by a *curtain*.

2 Without using any packing or drains, the wound with a wide dependent drainage opening is suspended in an air dressing and let strictly alone (method used in Böhler's Clinic)

3 The wound is packed lightly with fine meshed gauze. After four days the packing is removed and boric or normal salt solution compresses are changed four hourly and later six hourly until healing is under way Dressings may be changed once daily, but wet four hourly

A good alternative is to apply the wet compress at once, adding more solution to it until, commencing after 24 hours, it is changed four hourly without disturbing the inner packing On the fourth day the packing is removed and not replaced.

4 A wide-open wound may be packed lightly with fine meshed gauze A dry dressing is applied over this Subsequent dressings are done not oftener than once a week, and then under strict aseptic precautions.

5 At the primary treatment encircling

sutures of stainless steel wire are placed surrounding the wound, but not tied The wound is treated as in method three and on about the fifth day, when red and granulating it is gradually closed by drawing the wires together at once or on succeeding days. This principle may also be used with method four

6 Antiseptics are being used less, but still have a place Useful ones are boric compresses, 1 5000 acriflavine packs, Dakin s or hypochlorite irrigation, azorchloramide in triacetin 1 to 500, and merthiolate 1 to 5000 Many antiseptics destroy penicillin.

When a patient's body forces are insufficient to cope with an overwhelming infection the brief use of antiseptics can check the infection, though they will delay healing Also, they keep sweet the pus-filled dressings and may be used in them alone

7 For gas gangrene see Chapter 14, *Infections of the Hand*

Secondary Closure When a wound is sufficiently clean it may be closed If delayed longer, granulation tissue is built up at the expense of a healthy wound and after closing there may be drainage. In war surgery at present a wound is débrided, packed open lightly and wrapped in a pressure dressing Within ten days, usually eight, the first dressing is done in the operating room If the wound is clean, it is closed surgically The edges may be drawn together by suture or undermined and slid together as a plastic maneuver In some, a skin graft is used to cover over denudation At this operation fractures are set using traction and repairing them by the open method when necessary Parenteral penicillin is kept up for 10 days The British report remarkable results after secondary closure following one insufflation of the calcium salt of penicillin diluted 5 000 units per gram with sulfanilamide. The sodium salt which was not available they found to be even better Their statistics showed that there was a slightly greater percentage of success when penicillin was given parenterally than when it was locally insufflated A pressure dressing is always applied, because a collection of pabulum, such as hematoma, will prevent healing If a wound does not appear clean, it is treated by compressing and pressure for two or three days and then closed surgically If then, 1/8 to 1/4 inch of unclean surface is shaved off, the percentage of primary healing is much higher Fitness for closure depends on the appearance of the wound irrespective of the bacterial flora, bacterial counts being rarely used Granulations should be firm and red, not tender or prone to bleed, nor edematous, pale or overgrown There should be no gray or yellow spots of necrosis or sinus openings from tendon or bone. Epithelial borders, instead of being scalloped or undermined, should show a thin film of epithelium reaching out over the granulations Redundant granulations may be scraped off with a handle of a scalpel Pressure dressings make granulations healthy The use of penicillin is a great help in secondary closure.

Secondary closure is best done in three or four days, and, from then, diminishes progressively in its percentage of success (Porritt in reporting on 4,432 closures) With penicillin 94 63 per cent success was obtained and without it 84 61 per cent Rarely is drainage used. Adequate primary surgery favors secondary closure Wounds several weeks old, when excised and the skin undermined, yield more successful closure than when merely closed Even some moderately infected wounds may be closed, but only half of them successfully

Secondary closure of a large defect by direct pedicle flap from the abdomen gives a good result when the blood is fortified by penicillin against the spread of infection. It is time-saving and so reduces the stiffening of the hand

Subsequent Care of Wounds. Dressings should be infrequent. A wound heals better if not tampered with too often and reinfected, it is especially susceptible to

infection in the first five days, so it is advisable for the surgeon to use a face mask in dressings wounds during this period and not talk into a wound A wound in an air dressing needs no care, it becomes dry and aseptic. Even if not dry, a wound with good dependent drainage does well if let alone in the air

Healing is retarded by too frequent dressings, by daily applications of antiseptics, by infection and reinfection, by the presence of necrotic tissue or foreign bodies in the wound, by movement, and by the presence of dirt and débris in and around the wound Antiseptics may primarily reduce infection, but the tissues bathed in them take forever to heal. They are so injured that they can neither fight off the bacteria nor heal. The tissue cells must first be sloughed off so that reinforcements can do the healing Fingers or instruments passing unsterilized from wound to wound, disseminate infection, and so also does mouth spray These causes of infection may be unrecognized, as seldom do we reminisce as to cause and effect for several days back. I once saw the same rubber gloves used from case to case for the protection of the surgeon. The result was the infection of every patient.

Any piece of necrotic tissue lingering in the wound renders the whole wound dirty A foreign body may retard the healing. Very often healing is retarded by motion and splinting the flexion crease, or the part that moves results in prompt healing About wounds, even those that have been regularly compressed but not washed, there accumulate from neglect piled up crusts, old epithelium, hair, bacteria, and dirt that constitute abundant and excessive culture media If we but clean up the wound and surroundings, scraping off the débris from the skin with a spoon curet until only live tissue remains, the improvement in healing will be surprising In addition to changing compresses, the wound and the surroundings of the wound should be kept clean

Voluminous, wet, lukewarm compresses of boric solution, changed four hourly, soon make a clean wound. In a few days, to prevent sogginess, a half hour exposure to the sun twice a day and alternate periods of drying in air hasten recovery The compress should then be changed to normal salt solution for speedier growth. Darkness dampness, and uncleanliness infect, but light and dryness are beneficial. When dry, a wound surface contracts, drawing and leading the skin over it. Necrotic patches are touched with Burwick's dye or excised. A pus poultice eats Stitches in wet, dark places lead infection in Raw surfaces should be kept apart as they suffer by reflection. Raw creases should be held wide apart by adhesive bands and laces. If a wound is slow and edematous, such as an amputation stump, healing is greatly speeded by compressing the edema out by an elastic bandage.

Where epithelization is desired, penicillin may be used in ointment to keep the gauze from adhering to the wound. Growth of epithelium can be encouraged by cleanliness and providing a *smooth, overlying surface* along which to extend such as adhesive plaster, tissue strips, perforated cellophane, or a coating of Parawax sprayed on when melted.

Pressure by keeping down edema greatly improves and speeds the healing of wounds, and should be used routinely

Wounds in the young and healthy heal over twice as fast as in the aged and ill.

Splinting is maintained until danger of infection is over, good vitality has been established, and wounds have about healed. The hand should be kept always in the position of function. Only the injured part should be splinted and all of the rest or other digits should be free to move through their complete range. It is easier to avoid positions of nonfunction than to cure them.

Injuries of Nerves

If perfect facilities are present and early complete débridement is done, nerves may be accurately sutured, using the finest silk, with results even surpassing those of secondary suture providing they are done with the same skill Usually, and for the routine operator, it is better merely to fasten the nerve ends to each other with one stitch of fine silk or stainless steel wire, to prevent retraction Later, secondary repair will give better regeneration, as it will be more accurate and freer from cicatrix for not being in traumatized and potentially infected tissues. *Discussion of nerve injuries* may be found in Chapter 8.

Wounds of Joints

If treated early enough for débridement the joint should be washed with a forceful stream of normal salt solution and, after instillation of 1 000 units per cc of penicillin, closed, swinging a flap of skin over it if necessary The instillation is repeated as often as necessary Penicillin parenterally administered is less effective in joints Absolute immobilization must follow The general principles are detailed in the part of this chapter dealing with open wounds.

If it is too late for débridement and closure, the capsule should be closed or covered over by a flap and the wound packed open. Sutures may be placed for drawing together when the wound is clean

Treatment for infection of joints is found in Chapter 14

Primary Repair of Severed Tendons

Treatment of Wound Itself Severance of a tendon is an indication to hurry the patient to a hospital where good surgical facilities and surgical skill are available Without these, suture of a tendon should not be attempted as it does more harm than good. The fate of a tendon is dependent on the proper treatment of the wound as a whole, because a tendon cannot live long when either exposed or bathed in infection Therefore, when tendons are severed the proper treatment of the wound in general is essential in order to provide an environment for clean primary healing In a compound injury of a hand the outcome is determined by the selection of the primary *surgical procedure* Thus, the patient can be spared long illness and extensive crippling by preventing sloughing tendons, infected joints, and osteomyelitis This can be accomplished by observing the following three main principles

1 Early operation before the germs introduced have become numerous

2 Thorough débridement.

3 Covering over of all vulnerable tissues

A more complete discussion of these principles, so essential for primary suture of tendons, precedes in this chapter

It is preferable to suture tendons within six hours after the accident, that is, before the bacteria in the soiled wound have greatly multiplied. A tendon should never be sutured after 24 hours, for infected sutured tendons result in terrible infection that extends rampant up tendon sheaths and spreads through a limb, resulting in crippling Several fortunate primary reconstructions done under adverse conditions do not justify one such case. In many instances, however, the arbitrary six hour limit is unnecessarily short, because there are various determining factors other than time alone If such factors are favorable and a smear from the wound does not show cocci or an excess of pus cells, tendon suturing up to 12 or even 24 hours is possible. The judgment in this is based on the various factors already detailed above, and much depends on how the operation is done and on the after treatment.

As an arbitrary rule, the six hour limit is good, and even then the work should be done only by one skilled in this line. Ever[y] detail of the débridement and covering ove[r] of the vulnerable tissues should be meticu[lously] carried out. If the wound, even i

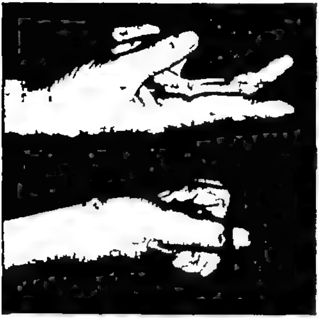

FIG. 520 Result of primary suture of flexor tendon in proximal segment of a finger with a stainless steel wire removable suture. (Courtesy Amer Jour Surg., 47 508 No 2 February 1940)

FIG. 521 Five hours after severance by a broken bottle in the palm, the flexor tendons to the index finger and the nerve to the second cleft, a primary suture of the nerve and each tendon was done using for the tendons removable stainless-steel wire.

In four and one half months sensation returned throughout and the index finger had full range of motion as shown in the illustration.

seen early, has already been through a futile attempt to repair the tendons, it is better to refrain from again operating and let the wound heal for later repair

Repair of Tendons. In disability cases coming late for reconstruction of solidly congealed and contracted hands, much of the destruction can be ascribed to the very bad infection that resulted from the additional trauma of surgery The tendons in these hands were often sutured after 24 hours following the accident, when bacteria were so numerous that they were spread and planted extensively through the hand and wrist by the surgery

Tendons should never be sutured if the wound is already infected, if over 24 hours old or even well within 24 hours if in the presence of too much crushed or damaged tissue, or if the wound is too dirt-ground or badly contaminated. Nor should the operation be done with poor hospital facilities or by an unskilled surgeon. It is preferable to leave the severed tendon undisturbed, so that it can be repaired later under good conditions, than to do what will make the limb worse.

In recovering tendons for suture a prevailing fault is to continue an incision upward along the tendon—namely, to make the "pernicious median longitudinal incision" that cuts across natural creases and pulleys and leaves maximal length of adhesions along the tendon, resulting in keloids, flexion contracture, loss of gliding surface, bowing forward of tendons, and immobility from adhesions. Instead, a small transverse incision higher up will suffice, or a midlateral one in the finger Care should be taken to avoid crossing flexion creases at a right angle or injuring small nerves. When there is a transverse or oblique laceration good exposure is best gained not by a longitudinal incision made at a right angle to it as a T, but by prolonging one end of it up the limb and the other downward so as to make a bayonet-shaped incision Flexing a digit passively causes the distal cut tendon end to travel an inch up the sheath. Pressure on the muscle above will make the proximal end protrude. In a sheath tendons retract farther than they do in paratenon formation, the healing is

and if occur it is

FIG. 522 Case P G Z. Primary repair of flexor profundus tendon of ring finger using removable stainless-steel wire. The hand had been pulled into a lathe gouging out the volar skin in the distal two segments of the fingers and severing the nerves and tendons in the ring finger in the proximal segment. The pulley in this segment was slit the flexor profundus united fastening the wire to a button outside the skin The nerves were sutured and the denudations of the fingers were skin grafted.

The illustrations show the return of range of motion seven months later Sensation returned to all but the extreme tip of the ring finger

worse. The use of a tourniquet is essential, as has already been stressed.

Healing of Tendons A clear conception of how a cut tendon behaves and heals helps in developing a method of suture. The healing is quite different when cut in paratenon formation, and different, too, when not sutured than when sutured If cut in a sheath the proximal end of the tendon retracts farther than when cut in paratenon In either case the distal end retracts only as far as it is drawn when the limb is extended The tendon ends if cut in a sheath do not proliferate any more than to become rounded over and sealed by epitenon, and they remain free in the sheath. If infection develops they become attached to the sheath and cicatricial

When cut in paratenon and not sewed each tendon end attempts to reach out and rejoin the other Extensive proliferation of the paratenon, epitenon, and endotenon or connective tissue elements reaches out like an expanded flame and attaches to anything it can From the natural process of healing, which has already been described, there is the great tendency for the tendon at its juncture to grow fast to the surroundings, and this tendency is stimulated by all factors which provoke tissue reaction, including both infection and surgical trauma. The more elaborate the suture, the greater will be the amount of foreign body material the more necrosis which develops from the grasp of the suture, and the worse will be the attachment It is clear that to obtain a free-running tendon healing should be as reactionless as possible.

The poorest results in tendon repair are of the flexor tendons in the narrow, firm tunnel or sheath extending from the distal crease of the palm to the middle joint of the finger

It is customary to obtain good results by silk suture of tendons in the forearm, where the surrounding tissue, if adherent, moves with the tendon This is true in the dorsum of the hand, where also tendons interdigitate, and it is often true in the palm, but in a flexor sheath in the finger failure is inevitable unless every refinement of method and delicacy of technic is used

Materials for Suturing Tendons. Of materials for suture catgut is the least satisfactory It is coarse and provokes so much reaction, sensitization, and otherwise that its use is followed by infection six times as often (O'Shea) as that of silk. Fine silk of three-pound test through the knot and untreated, is in general use but

though superior to catgut it causes considerable cicatrix about it. Fine, stainless steel wire Nos 34 and 35 provokes the least reaction of all suture materials. It is non electrolytic and lies inert or reactionless in the tissue. It slides well through the tissue and is, for its strength, finer than silk. A suture with No 34 will withstand a strain of five pounds. *Great care should be used* to avoid kinking the wire, as this will cause it to break I do not recommend that it be left permanently *in a tendon* in any region where the tendon angulates or moves, because the movement will then make some *mechanical irritation* unless, as often happens, the wire fragments into many short segments, which then do no harm It is *my contention*, however, that if this mate

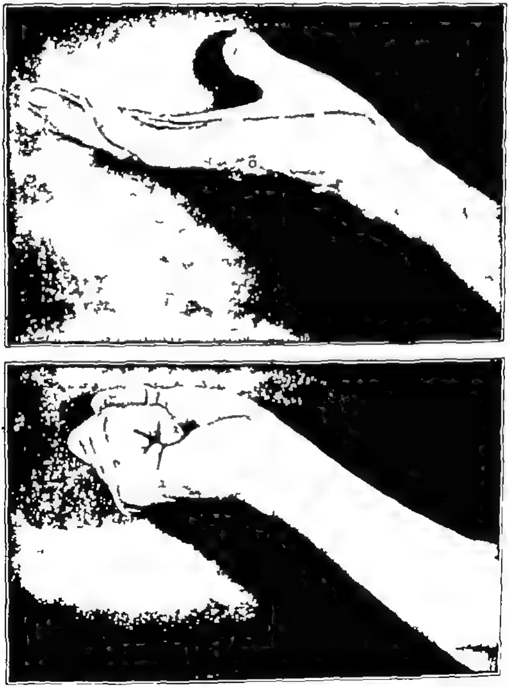

FIG. 523 Case G H. Result in case of primary repair of severed flexor tendons in little finger sutured in the proximal segment a part of the finger notorious for poor results. Removable stainless-steel wire No. 34 was used. (Courtesy Jour Bone and Joint Surg., 23.211 No 2 April 1941)

rial is used as suture and placed in such a way that it is removed in three weeks, by which time the tendon will have physiologically united, there will be the least irritation in and around the tendon The tendon ends will pull apart somewhat during healing There will be some central necrosis from this tightness, but it will eventually be replaced by tendon tissue

To prevent tendon ends from pulling

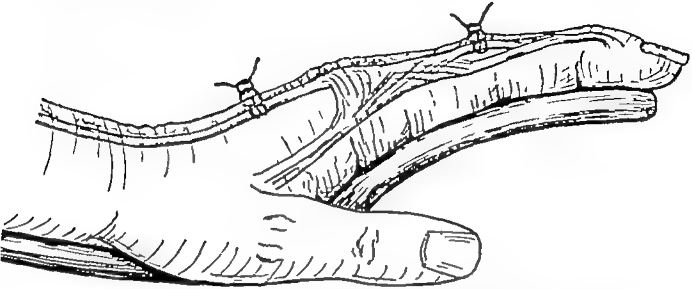

FIG. 524 For primary or secondary repair of extensor tendons a simple figure-of-eight stitch with No 35 stainless-steel wire is used. One loop unites the tendon ends and the other the skin edges. The stitch is without strength and is merely for approximation of tendon ends. Splinting as shown prevents tendon ends from being pulled apart.

juncture will then be free from any suture material which could by irritation provoke adhesions. This wire is preferable to any other suture for obtaining primary closure of wounds. It is always used removable, unless in a stationary place, and then it is interrupted. The choice of material for tendon suture is either silk or withdrawable stainless steel wire.

Type of Stitch. In the primary repair of tendons the stitch should be the simplest possible. In order to hold it must cross some fibers for a splicing effect, but this should be minimal A single stitch placed longitudinally or a pin through the tendon will split through on slight tension. A core suture is less likely to cause adhesions than one in which the suture is on the surface of the tendon The smooth, glistening epitenon surrounding the tendon should not be even scratched The suture material should be fine and largely sunk out of sight into the tendon. All slack should first be withdrawn by pulling the suture taut Otherwise the apart more reliance should be placed on splinting, with joints flexed to relax the tendons, than on the strength of the suture. In three weeks fairly strong physiologic union allows removal of the splint. Half circumference plaster of Paris is best for this. For flexor tendons it is molded on the dorsum of the hand and forearm with the wrist flexed, but with the digits free for some feeble action. For extensors, the splint is placed on the volar aspect and holds the wrist and digits in dorsiflexion The latter keeps extensor tendons so well relaxed that the only suture necessary is a simple figure-of-eight No 35 wire placed through the skin with one loop, and through the tendon ends beneath with the other This is kept in situ for three weeks. These extensor tendons so interdigitate that splinting alone often suffices, though accuracy of union gained by one stitch is advisable if we gauge our results critically

For flexor tendons in palm or forearm a useful quick stitch that holds fairly firmly

is the "double right angle." The needle is thrust straight through the tendon 4 mm. from the end, repeating in the other tendon end as in a simple longitudinal stitch, which in itself will not hold. Another similar stitch with the same suture is placed at a right angle to the first. The ends of the suture are then tied fairly tight. A smaller size suture can be used for this stitch, as four instead of two strands divide the strain The four strands also hold the tendon ends cage-like and in better approximation. The strength of this suture is due to crossing the tendon fibers in two quadrants but when used the tendon should be left in constant relaxation by keeping the wrist flexed by a plaster of Paris dorsal splint, as the juncture is not strong A pull out wire can be placed so the suture, in case of infection may be withdrawn, or if not, so the pull-out wire can be If the usual suture used in late tendon reconstruction is used for primary repair it should be simplified by penetrating the tendon fewer times and placing more reliance on splinting

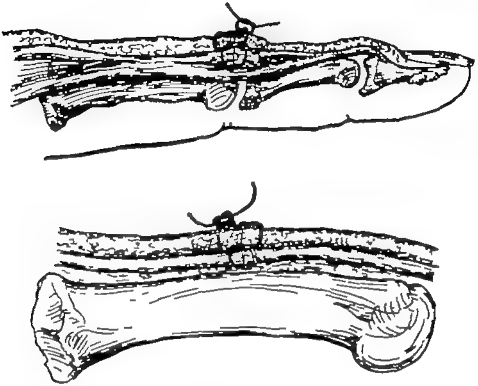

FIG. 525 (*Top*) Primary suture of severed central slip of extensor tendon with simple figure-of-eight stainless-steel wire relying more on splinting to prevent parting
(*Bottom*) Similar method of primary suture of tendon on dorsum of hand. (Courtesy Amer Jour Surg., 47 503 No 2 February 1940)

Withdrawable Tendon Sutures Convinced that complete absence of suture after the three weeks, during which the tendon has united, is most favorable for a free-running tendon, a method has been developed by which the suture can be withdrawn. A sutured tendon pulls from its muscle end only Therefore, the suture is spliced securely into this end and the two suture strands are passed some distance down through the center of the distal tendon and on out through the skin. By pulling upon these sutures from the outside and anchoring them securely, the proximal tendon end can be drawn down until it is approximated to its distal end. The tendon ends will lie passively in exact apposition. If, by chance, they do not only one tiny double right angle stitch of fine blood vessel silk is then necessary for exact approximation.

For the later removal of the stitch a pull out wire is left in place, which will draw the stitch out backward by its loop after the two stitch wires are cut off beneath the surface of the skin. Both ends of the pull out wire, after being placed through the loop of the stitch in the proximal tendon end are threaded on a needle and passed up through the sheath some distance and out through the skin so the play of the wires in the sheath will allow a little move ment in the tendon without strain on the juncture.

Tension is relieved by flexing the joints The stitch wires can be anchored to the outside of the limb by passing them through adhesive plaster applied to the skin and then variously tying them over a button or fastening them by a split shot or a loop of adhesive plaster over the end of the finger, or by tying the wire ends through a perforation in the fingernail. If any resistance is encountered when withdrawing the stitch by the pull-out wire, tension may be applied by fastening a light rubber band to the wire At the next dressing the stitch

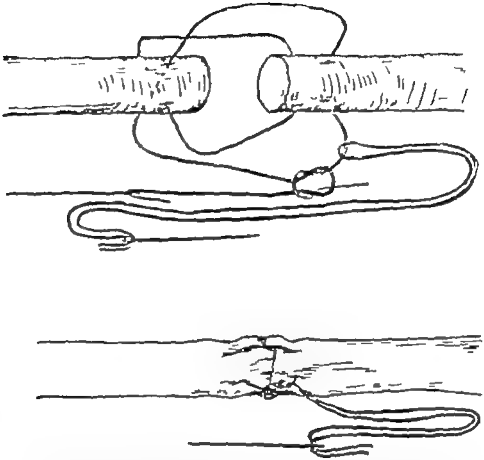

Fig. 526 Double right-angle stitch. This stitch is more than twice as strong as two simple through-and-through stitches because in each tendon end the stitch crosses diagonally a quadrant of tendon fibers. This displaces till somewhat on the bias as the stitch is pulled, all strands thus making for added strength. The four strands give a basket effect for better approximation of the tendon ends and divide the strain so that a smaller strand of silk may be used. The stitch is simple and quickly placed. To prevent breaking more reliance is placed on splinting the wrist in flexion to relax the flexor muscles than on the strength of this stitch. A pull-out wire is placed under the knot as shown, drawn out through the skin and left in place if deemed advisable. If infection develops later the stitch can be withdrawn as soon as the tendon unites or if healing is *per primam* the pull-out wire may be withdrawn. (Courtesy Jour Bone and Joint Surg., 23 209 No 2 April, 1941)

is the "double right angle." The needle is thrust straight through the tendon 4 mm. from the end, repeating in the other tendon end as in a simple longitudinal stitch, which in itself will not hold Another similar stitch with the same suture is placed at a right angle to the first. The ends of the suture are then tied fairly tight. A smaller size suture can be used for this stitch, as four instead of two strands divide the strain The four strands also hold the tendon ends cage like and in better approximation. The strength of this suture is due to crossing the tendon fibers in two quadrants but when used the tendon should be left in constant relaxation by keeping the wrist flexed by a plaster of Paris dorsal splint, as the juncture is not strong A pull out wire can be placed so the suture, in case of infection may be withdrawn, or if not, so the pull-out wire can be. If the usual suture used in late tendon reconstruction is used for primary repair it should be simplified by penetrating the tendon fewer time and placing more reliance on splinting.

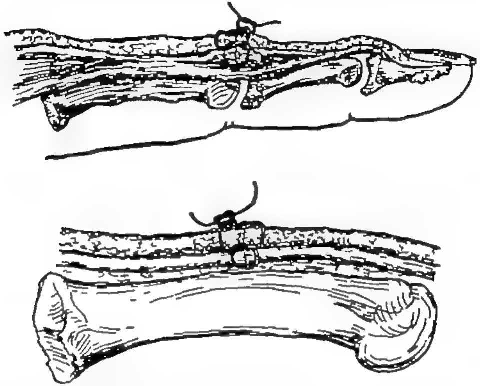

FIG. 525 (*Top*) Primary suture of severed central slip of extensor tendon with simple figure-of-eight stainless-steel wire relying more on splinting to prevent parting
(*Bottom*) Similar method of primary suture of tendon on dorsum of hand. (Courtesy Amer Jour Surg., 47:503 No 2 February 1940.)

Withdrawable Tendon Sutures. Convinced that complete absence of sutur after the three weeks, during which the tendon has united, is most favorable for a free-running tendon, a method has been developed by which the suture can be withdrawn. A sutured tendon pulls from its muscle end only Therefore, the suture is spliced securely into this end and the two suture strands are passed some distance down through the center of the distal tendon and on out through the skin. By pulling upon these sutures from the outside and anchoring them securely, the proximal tendon end can be drawn down until it is approximated to its distal end The tendon ends will lie passively in exact apposition. If, by chance, they do not only one tiny double right angle stitch of fine blood vessel silk is then necessary for exact approximation.

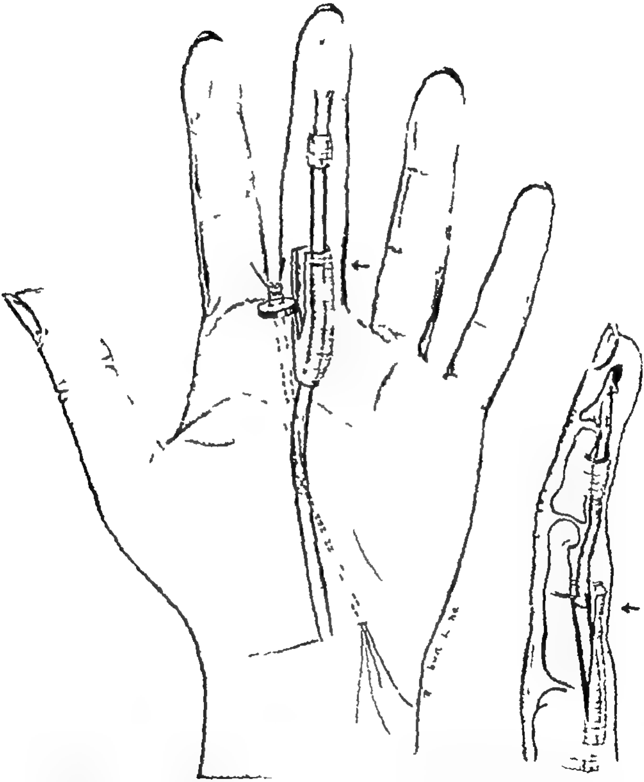

FIG. 528 Primary suture of flexor tendon between distal crease in palm and middle crease in finger (no man's land) Sublimis is removed or tendons adhere together Pulley is slit to allow tendon to swell in healing Tendon ends lay together (arrow) with nothing in the vicinity to provoke adhesions Stainless steel is used instead of silk to lessen the reaction. The suture is placed "at a distance" to be withdrawn later

goes necrosis Resolution of this results in converting all the tunnel contents into a firm cicatrix fused to the surroundings. (3) A silk suture provokes adhesions

Good function by suture here may be obtained if we adhere to all the following points. Strict atraumatic technic makes less adhesions Whenever cut between those

will be out. The bend of the pull-out wire, where it looped through the stitch, should be pinched very lightly so that it will not encircle tissue, but not pinched tightly because this will break it. Twisting it prevents tendon further proximally, in a place where the tendon will not adhere. It may be brought out through the skin and there anchored, so the tendon juncture will be relieved of any muscle strain.

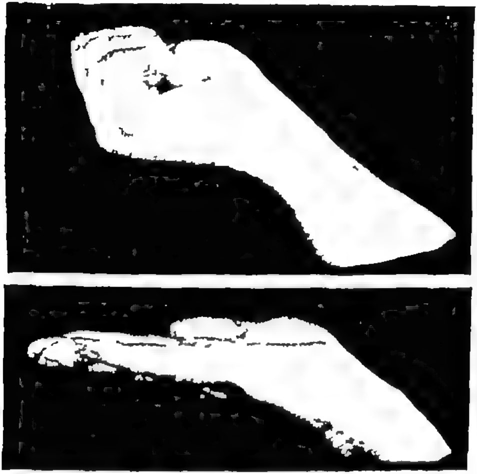

FIG. 527 Case E. M. Another case of primary repair of severed flexor tendons opposite the proximal phalanx. (Courtesy Jour Bone and Joint Surg., 23 212 No. 2 April, 1941)

looping If the double right angle stitch of silk is used it can in case infection is likely, be made optionally withdrawable by merely laying a pull-out wire across the knot as it is being tied. The two ends of the pull-out wire are then threaded on a single needle and brought out through the skin. If infection occurs the stitch can be withdrawn but if it does not the pull-out wire alone is withdrawn after cutting off one of its ends just beneath the skin.

This stitch may be made with very fine silk more for apposition than strength. To prevent breaking, a check suture of No 34 stainless steel wire may be placed in the

Suture of Flexor Tendon in Finger Poor results the world over follow suture of flexor tendons in what is called "no man's land' that is, between the distal crease in the palm *and the middle flexion* crease in the finger Let us consider what happens in this narrow tunnel Here the tendon juncture adheres in its bed for several reasons. (1) The sublimis and profundus *tendons adhere to each other* allowing motion of one joint only, the middle. (2) The enclosing firm tunnel does not allow for the necessary swelling of repair, the blood supply is squeezed out, and, consequently, *the tendon within* the tunnel under

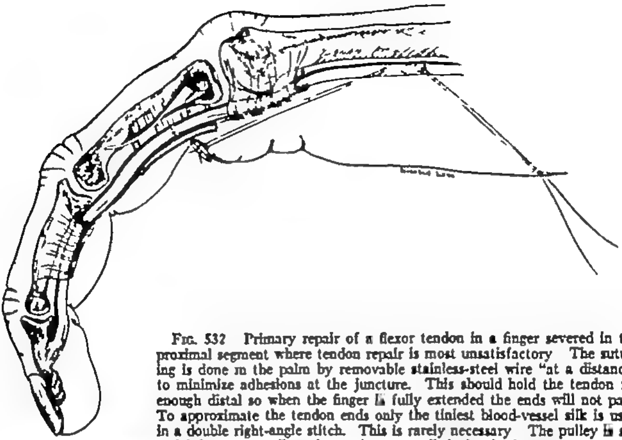

FIG. 532 Primary repair of a flexor tendon in a finger severed in the proximal segment where tendon repair is most unsatisfactory The sutur ing is done in the palm by removable stainless-steel wire "at a distance" to minimize adhesions at the juncture. This should hold the tendon far enough distal so when the finger is fully extended the ends will not part. To approximate the tendon ends only the tiniest blood-vessel silk is used in a double right-angle stitch. This is rarely necessary The pulley is slit and left open to allow the tendon to swell during healing.

FIG. 533 Case E. H. Primary repair of tendons and median nerve severed in wrist seven hours previously All flexor tendons to the fingers were severed except the profundus to the little finger

In nine months sensation to light touch and pinprick and some stereognosis had returned throughout.

The illustrations, taken a year later show complete range of motion.

vance the tendon to its distal stub by elon gating it at its musculocutaneous juncture. Preventing this, except for a slight degree, in the index finger 1 inch and in the others from ½ inch to ¼ inch, is a tough sheath of ulnar bursa, together with tendon inter digitations joining the profundus tendons together in their under surface and effectu ally preventing longitudinal advancement of the single tendon If this is freed by a stripper, adhesions will form However, the sublimis tendons can be advanced in this manner and joined proximally in the forearm to the profundus.

General Considerations. A tourniquet is always used, and usually block anesthesia but if the case is extensive general anesthesia is preferred. A complete oper ating room setup is necessary, just as in the work of reconstruction

If the flexor sublimis tendon is cut in a finger it need not be sutured, but if both flexors are cut between the two above men tioned creases only the profundus should

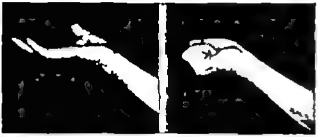

FIG. 529 Case G H. Primary repair by removable stainless-steel wire of flexor profundus tendon of little finger severed in the proximal pulley over the metacarpal head by sheet steel. The sublimis tendon was allowed to retract.

The illustrations, taken a year later show the degree of motion gained. The stub of the sublimis tendon left in the finger slightly limits extension of the middle joint.

FIG. 531 Case E M. Primary suture with removable stainless-steel wire of the flexor or profundus tendon of the little finger severed with a knife at the middle crease. The pulley in the proximal segment was slit and the sublimis tendon was removed. The nerves on the ulnar sides of the ring and little fingers also were sutured. Sensation returned in three months.

The illustrations show degree of motion gained, seventeen months later

FIG. 530 Case C. C. As a knife slipped through his hand both sublimis and profundus tendons and the radial volar nerve were severed in the index finger and the profundus and one slip of the sublimis in the long in the proximal segment of each.

Débridement and primary repair were done, using removable stainless-steel wire and "suturing at a distance" namely in the palm. In the index finger the sublimis tendon was removed and the nerve sutured.

The photograph shows degree of flexion in fingers seven months later Sensation returned He had 35 of voluntary flexion in the distal joint of the index and 40 in that of the long. With the index he touched the palm three fourths inch proximal to the distal crease in the palm and with the long finger touched the distal crease.

two creases bounding "no man s land," the sublimis tendon should be removed This, also, leaves more room in the tunnel for the profundus. The annular ligaments, or pulleys, should be slit through laterally to allow the profundus tendon to swell during healing with freedom for circulation. Instead of silk, a suture should be selected which will be the least irritating, namely stainless steel The suture should be placed in one tendon end only, as only that attached to the muscle pulls, the other end being passive. One step further is to leave the tendon juncture free from any suture or trauma by placing the suture at a distance The tendon is uncovered in the palm and there a stainless steel wire is spliced in bringing it out to tie to a button at the plica of the palm. This holds the tendon distalward It should be fastened far enough distalward so that when the finger is straightened the two tendon ends will not separate. A pull-out wire is placed for withdrawal of the wire in three weeks. The tendon ends will lie in approximation and heal under conditions of the least disturbance that might provoke adhesions. If the finger may be so extended or flexed that the juncture is away from the laceration, it will have less tendency to adhere

Advancement of Tendons Down the Hand In severance of a profundus tendon in a finger it would seem plausible to ad-

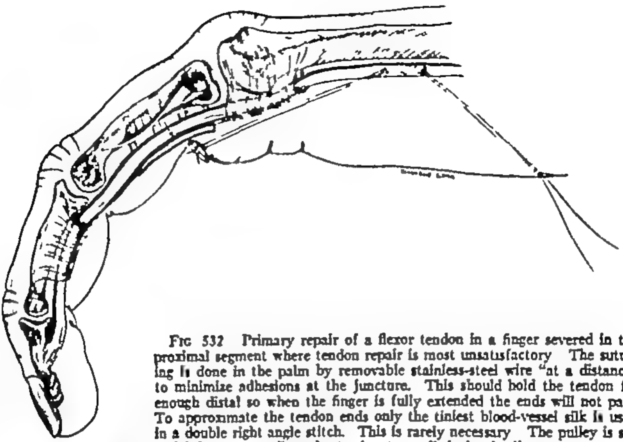

FIG 532 Primary repair of a flexor tendon in a finger severed in the proximal segment where tendon repair is most unsatisfactory The suturing is done in the palm by removable stainless-steel wire "at a distance" to minimize adhesions at the juncture. This should hold the tendon far enough distal so when the finger is fully extended the ends will not part. To approximate the tendon ends only the tiniest blood-vessel silk is used in a double right angle stitch. This is rarely necessary The pulley is slit and left open to allow the tendon to swell during healing.

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General Considerations. A tourniquet is always used, and usually block anesthesia, but if the case is extensive general anesthesia is preferred. A complete operating room setup is necessary, just as in the work of reconstruction.

If the flexor sublimis tendon is cut in a finger it need not be sutured, but if both flexors are cut between the two above mentioned creases only the profundus should

FIG. 534 Case F E H.
Primary suture of flexor tendon in proximal segment right ring finger four hours after lacerating in a fall while holding a crockery jug by the handle. The nerve on the radial side was sutured. The sublimis tendon which had been severed was removed The profundus tendon was sutured with removable stainless-steel wire "at a distance" at the base of the proximal phalanx.
The illustrations show extension and flexion two and one half months later Sensation also had returned.

be repaired and the sublimis should be removed. If both tendons are sutured they will adhere to each other and thus act on the middle joint alone, but not on the distal joint. The profundus tendon sutured in the *middle segment of the finger may yield a* fair result, as it need pull through but one joint instead of two as in the proximal segment. Also, if it adheres it may later, with some advantage, be freed. A flexor tendon sutured at its insertion gives a good result. Flexor profundus tendons are essential for good *function, but sublimis tendons are not* so important. They help the muscle balance of the fingers and furnish the final tight clenching. Severance of flexor tendons in the proximal segment of a finger and distal inch in the palm is not only the most common injury but is followed by the poorest results. When the problem of repairing a flexor tendon at this site is solved, the repair of all tendons will be comparatively easy

Flexor tendons severed in the palm proximal to entering the annular sheaths over the metacarpal heads yield good results when sutured. Both sublimis and profundus should be sutured and separated from each other by the lumbricales. Often where the surrounding tissues are loose enough to glide, as in the forearm or base of the palm fine silk may be used, but where the only chance for gliding will be to have minimal reaction, as within a finger, or in any narrow tunnel, the use of a removable stainless steel suture is indicated. Multiple flexors or extensors severed at the wrist are very successfully repaired primarily The result is often excellent, and far better than when left unsutured for later secondary reconstruction. *Usually silk* or Fagersta * sutures are used, as here the junctures are many and the gliding problem is not so acute

For an extensor tendon severed on the dorsum of the hand a good result is obtained by a single figure-of-eight No 35 *wire suture for skin and tendon, together* with splinting wrist and fingers in extension

On the dorsum of a finger similar technic is used, but with extreme delicacy

Summary Primary healing of tendons in open wounds is dependent upon obtaining primary healing in the wounds in general. Essentials are prompt operation, thorough débridement, covering over all vulnerable tissues and adequate after treatment consisting of splinting, pressure, elevation, and dryness The technic of tendon suturing is based on physiologic repair, and striving for *reactionless healing and the least adhesions* by minimizing suture material and even at times suturing at a distance.' Removable stainless steel wire is superior as a suture material Irritation from suture is terminated by withdrawing the suture from the tendon in three weeks The fascial tunnel or sheath in the proximal segment of a finger should be split laterally when repairing a tendon within it.

SPECIAL TYPES OF WOUNDS

Puncture Wounds

The many minor punctures from small, fairly clean points heal kindly without

* Fagersta is a fine twisted stainless steel wire size 3 x .08 mm Being flexible mechanical irritation is avoided so it may be left in the tendon. Per strength it is finer than silk and does not irritate.

treatment. A major puncture from a large object needs laying open, débriding, closing, or leaving open for drainage. Between these are punctures of varying severity, depending on the contamination, size of puncture, likelihood of foreign body, and whether or not a vulnerable part has been penetrated. Judgment is needed to decide the correct treatment.

Nail punctures, so frequent in the sole, are treated successfully by making a small crucial incision at the wound of entrance and clipping off the four skin points so made. This allows drainage, and the method is applicable to the palm. Grossly contaminated punctures, with virulent germs as would be found in garbage, sewage, old meat, shellfish, or from a human bite, call for surgery. For punctures of uncertain outcome we can conservatively watch and wait early to detect signs of infection and promptly drain. Meantime, we should splint the member and keep it warm with compresses until it is no longer tender. This is particularly important if the puncture is in the dorsum over a finger joint or in a flexion finger crease over the tendon sheath. If from a sliver, flying glass, or a blunt object through a glove, suspicion of foreign body justifies exploration. This becomes necessary if the wound remains sore and shows flare-ups of infection. From even a narrow puncture by a sharp object there may be overlooked a severed nerve, tendon, or blood vessel. The latter may cause a hematoma or rarely an aneurysm, either arterial or arteriovenous. These two may be excised, as there is abundant collateral circulation.

Contusions

From a blow or a crush swelling follows from hemorrhage and edema. Early compression by bandage over voluminous dressings and elevation limits these. Splinting by the dressings is of benefit until the swelling subsides, and then there should be movement. Routine roentgen films may disclose fracture. For intense swelling in the forearm, the deep fascia should be split for the length of the muscles and should be freed about the vessels entering the antecubital space to avoid ischemic contracture.

Crushing of a metacarpal head or other spongy bone may lead to prolonged soreness and stiffening, which can be lessened by early splinting. From a crush through the dorsum of the hand the highest point, the styloid process of the third metacarpal, may remain enlarged, sore, and because of the attachment there of the extensor of the wrist, pains on gripping. Splinting in dorsiflexion places the tendon at rest. If, from severe crushing, there is necrosis of skin the area should be excised early and skin grafted.

Abrasions or Brush Burns

In a brush burn the skin becomes necrotic, superficially or completely, showing multiple scraping if from a rough object and often with ground in dirt. It is a combination of a wound and a burn. The necrotic surface becomes infected. Treatment is to cleanse with soap and water and remove the dirt, even scrubbing or shaving off a thin layer and then treating it as a burn.

Hematoma

Hematoma in the dorsum of the hand from a crush will usually be absorbed, but may leave fibrous thickening. If in palm or wrist an artery is lacerated the hematoma should be removed and the vessel ligated. If the hole is lateral, the artery should be severed and ligated on each side or bleeding will recur. The deep arch between the first two metacarpals is awkward to tie.

In subungual hematoma, shaving a hole through the nail gives instant relief. A pulp space tight with hematoma should be opened, to protect the phalangeal diaphysis from necrosis. Devenish reported two cases of hematoma in the flexor tendon sheath of the thumb, followed by pain, swelling, loss of motion, and recovery.

Effect of Vibrating Tools

From continued vibration from pneumatic drills or hammers a condition is produced known as "dead hand" Affecting mostly the left third, fourth, and fifth digits which hold the hammer, the limb seems to be the site of vasospasm. Cunningham reports decalcification and cyst formation, especially in the carpus, swelling and tenderness of the proximal and middle finger joints, stiffening of the fingers, and slight swelling and redness of the hand The skin is moist and shows vasospasm, or Raynaud's phenomenon, particularly in response to cold

Injuries from Porcelain Faucets

From breaking of a porcelain faucet in the hand, usually of the hot water pipe and working stiffly, the palm is lacerated in the *neighborhood of the flexion creases, gener*ally severing some of the flexor tendons and nerves to the thumb and first two fingers. Fortunately, the wound is usually clean, so prompt primary repair of the severed structures should be done but, if not treated early then late repair after healing These injuries which were very common are becoming less so, as laws are being passed in many states against the sale of porcelain faucets. All such faucets should be replaced by metal ones.

Injuries from Glass

A common injury from breaking windows or windshields is the severance of all of the tendons, vessels, and nerves across the volar aspect of the wrist, requiring a most tedious primary repair If not repaired primarily, after which good results frequently follow, the retraction of the muscles makes later repair most difficult. Falling, when carrying a glass bottle, terribly lacerates a palm or wrist Children should never be sent on an errand with a milk bottle.

Buzz Saw Injuries

From distracted attention, a crooked piece of wood or a jamming of the saw in the wood cut, the hand of even the skilled worker may eventually be drawn into the blade. Instantly, there is severance of every structure in its path Commonly the cut is oblique, partially through the radial or ulnar borders of the digits, hand or wrist, and infection may follow Later, extensive reconstruction of the tendons and nerves may be needed

Pulley and Belt Injuries

The hand may be drawn in up to the shoulder, and as it wraps around the pulley the bones are fractured along the length, depending on the diameter of the pulley Only the hand may be caught, injuring the wrist by the twisting pull, and in some of these cases the brachial plexus is injured from traction.

Injuries from Rollers or Hot Mangles

The hand and part of the arm are drawn in between the rollers and compressed. The rollers, continuing under power, may avulse a complete gauntlet of skin In others there is extensive contusion or crushing of the prominent bony parts. If hot, the skin of either surface of fingers and hand is badly burned, leading to contractures, often the fingers being drawn into the palm. In a personal case the arm rolled in, and on reversing the machinery and rolling it out the palm burst open and half of the flexor muscles of the forearm shot out, hanging by only their tendons. They were excised and the remainder of the hand made a good recovery

A gauntlet should be at once cleansed and replaced It is treated as a whole-thickness graft, the subcutaneous tissue being entirely removed and pressure and splinting maintained. If the original skin is not available a split graft is used. A flat piece

severe. The hard, fibrous, granulomatous, grease-filled tissue infiltrates diffusely, necessitating most careful dissection to spare blood vessels, nerves, and tendons Amputation of a digit or more may be necessary

Foreign Bodies

The foreign bodies commonly in hands are broken needles, splinters, thorns, glass, porcelain, rocks, silk sutures, sequestra of bone or tendon, pieces of glove, grease, chips of flying steel, shell fragments, bullets, shot and wads from blank cartridges To prevent or cure infection they should be removed In prolonged sinuses or repeated flare-ups of infection, foreign body is the usual cause. Also, it may long remain latent and then cause a sudden infection at the site. Foreign bodies predispose to tetanus. Small ones, such as bird shot, often are left in and do not cause trouble. If there is motion of the tissue, the foreign body will irritate Certain materials, such as splinters and thorns, irritate more than metal and provoke much surrounding inflammatory cicatrix. Proximity to a nerve causes pain and to skin makes tenderness. Some glass and porcelain cast roentgen shadows. Needles and thorns, due to movement, travel, necessitating up-to-date localization

Accurate localization is essential before removal. Lateral and anteroposterior x ray views must be taken exactly at a right angle. For a guide, the bones of the hand are usually sufficient but a wire cross may be fastened to the skin. In war hospitals near the front, the fluoroscope instead of films is used marking on the skin the lateral and anteroposterior positions, and with a ring the near point which, when pressed moves the foreign body the most. Also, a note of description of the body is made on the chart. Under the fluoroscope, a needle inserted to the foreign body as a guide may be left in place. By slowly rolling the part one gains, by parallax, orientation of depth The spot of maximum tenderness also guides.

If localization is exact the body is easily found, exposing it under the ischemia of a tourniquet. If linear, the knife should aim to cross it. Good palpation sense comes through a knife point, but if one feels with a finger, the foreign body seems to be missing, for under the fluoroscope it may be seen to dodge about the finger tip each time the latter touches the capsule enveloping it.

Metacarpal Boss

A tender, painful, bony swelling occurs on the dorsum of the wrist which is seen by lateral roentgen view to be bony proliferation of the dorsal lips of the capitate-metacarpal joint. There is pain on gripping and dorsiflexing the wrist against resistance because the tendon of the extensor carpi brevis inserts here on the third metacarpal, and pain on extreme dorsiflexion because of the exostosis The extensor tendon of the index finger may snap back and forth over it producing pain The condition is from traumatic periostitis, and occurs here because this part stands up so prominently that it receives the blow or crush. It may, also, hypertrophy from over use of the muscle that inserts into it. Excision does not help as it involves the insertion of the tendon. Splinting in dorsiflexion relieves the pain

Gunshot Wounds

These wounds are serious because the fragmented, exploded, necrosed tissue and the presence of foreign body, deep and under anaerobic conditions, furnish ample contaminated culture media and low tissue resistance for severe infection by pyogens, plus the Clostridiums of gas and tetanus. Joints and bones are shattered and muscles are disrupted. Tendons may be shot apart or subsequently destroyed by slough and cicatrix. Nerves are often paralyzed and to any degree but from gunshots the ma

jority recover, due to only partial severance or to distraction from being in the proximity of the bullet tract Over two-thirds of the gunshot wounds treated are of the extremities, as those of the trunk often kill build up the deep tissues, bones, nerves, and tendons

Gunshot Wounds in War Hands occupy a percentage of the area of the silhouette of a man, so in war there will be

Fig. 535 Fresh wound from high explosive A direct pedicle was applied and the exposed bone was saved (Courtesy of Thomas Cronin Lt. Col., M C.)

that percentage of wounds of the hands, and, in addition, hands are particularly vulnerable to hand grenades, personnel mines and flash burns. Grenades and mines may cripple both hands as well as the face and eyes Wounds from them include a large portion or all of the hand High explosive wounds from shell fragments do great damage Being blunt, and often cubic they punch in with them dirt, skin, glove or clothing, and being hot there is found a pocket of cooked tissue about them making an ideal set up for Clostridia. Rifle and machine gun bullets penetrate, rarely lodging in the hand The wound of entrance is small and that of exit is, also small unless shot from nearby Any bone in the path is fragmented into multiple pieces Some of these wounds are self inflicted, typically entering the palm at the left fourth metacarpal. Rifle bullets usually do not cause infection unless fired at close range

In a hand the important structures are

Wounds from Blank Cartridges. Blank-cartridge wounds are usually received in the left hand during sporting events or Fourth of July celebrations. The skin is powder-burned and the wound is ragged and necrotic. The dirty wads do not penetrate through, but are imbedded as foreign bodies, so predisposing to gas and tetanus infection that complete excision and prophylactic treatment are essential

Civil Gunshot Wounds In civil life gunshot wounds of the hand are usually from close up and are of the hand and wrist from resting them over the muzzle of the gun, or upward through the forearm due to dragging the gun toward one. Rifle wounds destroy a narrower zone, but from a shotgun there is wide destruction of every tissue in its path, and this is usually followed by infection. The tissues are filled with shot, many of which will become encapsulated and will never be recovered. In late repair it is first necessary to replace the skin by the pedicle method and then to

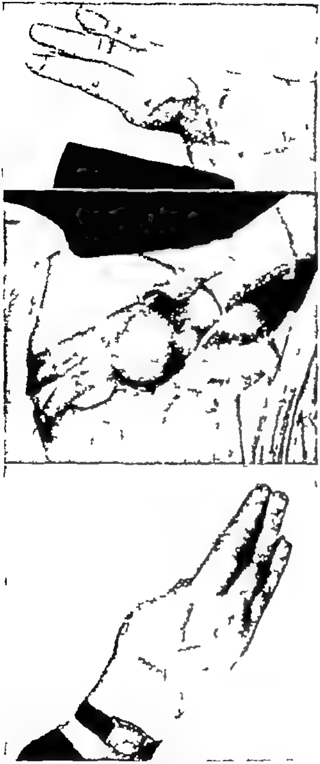

FIG. 536 Steps in closure of gunshot wound (delayed a week) by direct application of abdominal pedicle under the protection of chemotherapy (Courtesy of Thomas Cronin, Lt. Col., M.C.)

so closely packed that a gunshot wound through it cripples extensively Fractures of metacarpals upset the mechanics. Extensor and flexor tendons are injured Sensory and motor branches of the median and ulnar nerves may be shot off and intrinsic muscles damaged. Also, such structures around the missile tract become bound in cicatrix. A constant serious complication is stiffening of the proximal finger joints in the straight position Also, the whole hand assumes the position of nonfunction The majority of war-crippled hands are of this type. Others injured by personnel bombs, hand grenades or high explosives show amputation or great defects, marginal of either half of the hand, or central Many, especially in the Navy, are badly burned, particularly on the dorsum. Another large percentage of crippled hands is from gunshot wounds of the brachial plexus and the nerves of the arm causing hand paralysis with deformity, stiffening and poor nutrition.

The following is a plan of treatment in the Theater of Operations The wounded hand receives only a dressing and bandage in passing through the Battalion, Collecting and Clearing Stations, and in these penicillin is started. At the Evacuation Hospital the limb is rendered ischemic by having the blood expressed from it with an Esmarch bandage and having a pneumatic tourniquet applied The wound is then cleansed with soap and water, and it is débrided A thin layer of damaged surface is excised, and the physician removes foreign bodies, avoiding cutting nerves, vessels, joint capsules or tendons The wound is irrigated with salt solution. The tract of a shell fragment should be clipped away with scissors, and pains should be taken to excise all of the terminal pockets of cooked tissue and to remove the foreign body Previous localization of the later in two views, marking the skin accurately, is of much help For rifle bullet wounds it is only necessary to débride the wound of entrance and that of exit unless the wounds were blasted at close range. Gauze is placed loosely between the fingers and the hand is put up in the position of function enveloped

in a voluminous dressing of gauze fluff or waste around which is wound an elastic cloth bandage with enough pressure to prevent edema and give firmness A volar plaster slab is placed on the outside, never an uncut circular cast The hand is kept elevated As a rule gunshot wounds of the hands should not be closed until secondarily, but recently in selected cases primary closure was done. Face wounds are closed primarily and the hand is similarly vascular These hands were spared the open wound and healed retaining their mobility

From the Evacuation Hospital, after this initial treatment, the soldier is sent back to the General Hospital where, at the time of the closure six to ten days later, the repair work is done. Here fractures are set and wounds are closed, sliding skin flaps or skin grafting when necessary Fractures should be set with the hand in the position of function and under traction by the Böhler method as described in the chapter on Fractures A cast on the hand and forearm is the foundation for curved wire or metal extensions that support the injured digits and provide traction The casts are of part circumference or bivalved unless swelling is over When swelling is imminent, surrounding circular casts are too dangerous. The whole bony alignment of the hand should be correct at this stage of the treatment, and from there on attention should be concentrated on keeping the hand in the position of function and keeping the whole hand mobile

Gunshot wounds received late and infected are in immediate need of drainage and penicillin Excision would be dangerous at that time but when under chemotherapy, the infection subsides it is possible to excise the wound surface, necrotic tissue, dead bone and foreign bodies to set fractures and to bring the wound edges together An open wound or smoldering sinus stiffens a hand

Traction has so often been incorrectly applied, both in placing the wire and in

FIG. 537 X shaped incision commonly seen after gunshot wound through palm. Makes repair difficult as in this case a pedicle graft was necessary In such wounds extensor tendons are usually adherent or missing and the proximal finger joints are stiff and straight. (Courtesy of L. D Howard, Lt. Col., M C. Wakeman General Hospital.)

pulling at a wrong angle, resulting in much damage, that directions for its accomplishment should be studied If the position of fractured metacarpals and phalanges be corrected at this stage, much crippling will be prevented. If the traction is applied with the proximal finger joint in flexion, the collateral ligaments will remain elongated and later the joint will be able to move If these ligaments are allowed to shorten the proximal joints will become stiff and straight. Correct rotation of the bone may be ascertained by observing the planes of the finger nails and the plane of flexion of each of the fingers. Planes of motion should converge to the tubercle of the scaphoid. Attention to position of fractures saves the necessity in the reconstructive treatment of correction by osteotomy Early closure lessens induration and flexion contracture All undamaged parts should move Splinting continued too long stiffens hands Most metacarpal fractures unite within a month. Maintaining the position of function, namely, wrist in dorsiflexion, proximal finger joints flexed and other finger joints slightly flexed, metacarpal arch curved and the thumb in opposition, together with persisting in active motion of all of the uninjured digits, will save months of disability Special care should be used to keep the proximal finger joints in flexion and so prevent stiffening

Hand Cases in Zone of Interior in World War II By November, 1944, there were thousands of cases of crippled hands scattered through our General Hospitals, awaiting reconstruction. The management of hand cases stood out as a bewildering problem as knowledge of hand reconstruction was not widespread. There was every conceivable deformity of nonfunction, rigid joints malunion and cicatrix, but most of the wounds were closed. In the beginning of 1945 the severe hand cases were largely concentrated by the Surgeon General in nine General Hospitals and men were selected to care for these cases Selection was based on their interest and knowledge of hand surgery and their ability to cover all the three fields of extremity surgery,—plastic, orthopedic and neuro There were not many such available and some of these were beyond reach or overseas Enough were found so in each hospital the hands were being attended to, but the number of injured hands was so overwhelming that these men had to work to the maximum of their ability to accomplish the task. It was the writer's good fortune to serve as the Consultant to the Surgeon General for hand surgery and to have the opportunity to keep in the midst of this work. All the knowledge as it developed was pooled and passed on to every surgeon in this work Of the 600,000 wounded in the war, 24 per cent of wounds were in the upper extremity, of which hands constituted about 24 per cent or 6 per cent of all wounds. Of those wounded, three-fourths returned to duty *In addition injuries of brachial plexus and* arm nerves presented serious hand problems. A conservative estimate is that 20,000 hands needed attention. It was to the credit of the Surgeon General Norman T Kirk, that this was the first of wars in which reconstruction of hands was recognized and segregated as a special entity Consequently many men developed the ability to do this work and they became enthusiastic in striving to restore function to crippled hands. In January, 1946, these men gathered others interested and founded the American Society for Surgery of the Hand. Each operating surgeon, with one assistant and a ward surgeon, can readily care for 100 hand cases and operate on two or three hands a day averaging 50 or 60 hands a month These operations require much time. Usually one team has had to care for 200 and even 300 cases It was of great advantage to have, in the same hospital, all three extremity specialties. The interchange of ideas in each field was stimulating and made for a correlation of the specialties.

A survey of the hand cases received was

impressive in pointing out certain points for early treatment that, if corrected, would save disability Some hands were limber and many more were stiff The limber ones gave history of early closure of wounds, early correct setting of fractures and of much activity of the hand Usually their proximal finger joints had been put up in flexion and the hand in the position of function Stiffness in hands came from long edema and immobility Casts had included digits instead of stopping at the distal crease and the thenar crease in the palm The wrist had been held in flexion throwing the hand into the position of nonfunction Most wrists had been put up straight instead of dorsiflexed to 30 degrees The proximal finger joints had remained straight so their collateral ligaments became short and thick, preventing flexion Some had been passed through from station to station, at none of which did anyone assume the responsibility of removing the cast Some very stiff fingers had been put up straight in banjo splints It was often wished that there had been a special detail accompanying the homecoming soldiers to see that they used their hands and kept them moving There was much malunion from the digit not having had traction in the first three weeks of healing From this there was sharp buckling of metacarpals Other bones and joints were angulated, throwing the hand muscles out of balance and necessitating correction later by osteotomy Fingers often showed crossing or divergence on flexion from not having had the rotation checked by the planes of motion and the planes of the finger nails Omission of the above common errors of early treatment would have spared these hands from much reconstruction

The usual problem presenting was to replace cicatrix by good pedicle skin, a method commonly used being the one stage abdominal flap Tube pedicles were needed for special areas. Joints had to be slowly bent into positions of function For this spring or elastic splints were developed as they were more efficacious and provided exercise The metacarpal problem was the commonest, due to gunshot wounds of the meta

FIG. 538 Typical rifle wound through hand some of which are SIW The prevalent but unfortunate habit of making a stellate incision makes plastic repair difficult. (Courtesy of L. D Howard, Lt. Col., M C. Wakeman General Hospital)

carpal which involved the many surrounding structures and stiffened the proximal finger joints. The latter were almost universally stiff from lack of splinting them in flexion A great number of these joints needed capsulectomy, and many, arthroplasty *Of bone grafts*, those from ilium were most popular for metacarpals, and from fibula for forearm bones Grafts in metacarpals were pinned solidly in place so capsulectomies of the proximal joints were done at the same time. Operations on the wrist consisted of arthrodeses, resection of one or two rows of carpal bones and excision of the head of the ulna. Forearm bones needed realigning and grafting

Usually, after placement of the pedicle skin flap, the bones and joints were aligned for proper mechanics. The nerves were repaired as early as possible, and often wide gaps were overcome by many methods. Many nerves were sutured within the hand Tendon grafts were used routinely Paratenon and smooth surface of deep fascia were interposed for gliding Tendon transfers were resorted to especially for radial palsy and for paralysis of the intrinsic hand muscles. Hands with large defects required much reconstruction of new digits and placing of digits so they could oppose each other for prehension In absence of fingers, by phalangization metacarpals were used to act as digits.

Many cases of Volkmann's ischemic contracture resulted from injuries at the elbow in forearm or of the great vessels requiring arthrodesis of the wrist and transference of the remaining available tendons. From injuries of brachial plexus and arm nerves, hands became so rigid in the deformity of nonfunction that it was essential to start early treatment of the hands keeping the joints mobile by physiotherapy and in the position of function by small elastic or spring splints These held the hand in the correct position and substituted for the paralyzed muscles (Chaps. 4 They furnished exercise and did not

fere with occupational therapy Many such hands were worse from lack of splinting, and some had been pulled into deformity by over-splinting Rigid splinting makes rigid hands The hands atrophic from nerve plus vessel injury were a serious problem. Often they were so congealed, rigid and poor in nutrition as to be irrevocable. Amputation is preferable to a nonsensitive, immobile hand. Causalgia was common, but yielded in the main to sympathectomy

Injured hands that were used were the ones that limbered. Soldiers were stimulated to use their hands throughout the day In convalescence occupational therapy proved to be of great value in rehabilitating the crippled hand. Passive physiotherapy had a limited use, but the greatest help was from occupational therapy (Chap 7) Throughout the Army General Hospitals there was, in this field, great activity and development. See Chapter 7

The American Society for Surgery of the Hand will carry on and I hope will stimulate hand surgery The following presidential address * was delivered by the author at its inaugural meeting January 25, 1947

It is a pleasure to see the American Society for Surgery of the Hand established and on its way This Society was born from the enthusiasm of the officers of the late War, who reconstructed the hands of our wounded. It was found by many that hands could be reconstructed and that the results were good.

Why are we banded together in this Society? What is the interest that we share? It is in part the search to overcome the difficult, as a chase for the will-o the-wisp We are beginning to catch up with it, we are commencing to learn how to reconstruct such an important and indispensable organ as the hand We have found that the more we delve, the more fascinating becomes this field. It is vast and ever expanding including as it does most of the ailments of the extremities and of all of their tissues and structures. There is plenty of room in this [illegible] for mental acrobatics, the subject [illegible] iently wide to [illegible] 'py a man s [illegible] In diagnosis

* Courtesy of the [illegible] and Joint Sur[illegible] July 1947

alone, there is much to learn and much that is alluring It is fascinating to plan and to carry out an extensive reconstruction This involves all the mechanics of the hand and the action of the nerves and vasomotor system, bringing useful motion, sensation, and nutrition. It is the big field of surgery of the extremities in miniature, and includes all the principles of these tissues It is the jewelry of orthopaedic surgery There is also the human interest—the social side—for most men earn their living by their hands How much it means to the patient to restore to him what he has lost when that loss is the use of his hands!

Our Society is composed of men with a kindred interest, for mutual benefit for altruism, not unionism and to increase and disseminate knowledge of the hand in every phase of hand surgery We should encourage men to enter this important field, and should promote research in it.

A function of this Society should be to maintain an evaluation bureau or registry to determine and tabulate all methods, and to promote those which yield the best results Another function should be to maintain a committee to aid research workers. It could act in an advisory capacity, encouraging them in meeting problems, and also in coordinating and in preventing duplication of work. Stimulated by our common goal of advancement, we will find many other ways to further surgery of the hand

Surgery of the hand has lagged behind in surgical progress. Surgery of the foot which started with wrenchings and tenotomies, has gone ahead. It was not from any lack of importance that surgery of the hand lagged The obstacle was that the repair of the hand presents an intricate complex problem Reconstruction of hands is now successful, as shown by the fine results achieved by the many men who did this work in the Army and elsewhere In nine General Hospitals, to which the care of hands was assigned many thousands of hands were treated For the first time in any war, through the foresight of Surgeon General Norman T Kirk, in our Army hands were treated as an entity This viewpoint of having hands repaired by men trained in this specialty, hand surgery was responsible for the good results

In the mass production of these systematized hospitals it was demonstrated thoroughly that the hand should be treated as an entity and it is hoped that this classification, the merits of which have been proved in this War, will be perpetuated This applies also to organized civilian hospitals and to private practice

The hand specialist is not a tissue specialist, his work is regional or anatomical, just as with the specialties of eye and ear, or nose and throat His background must include the fields of the three tissue specialties—plastic surgery, neurosurgery, and orthopaedic surgery—and he must treat the region as a whole Hand reconstruction is intricate and it cannot be learned in a few months It should even include rehabilitation and the social aspects

The hand as a mechanical unit starts at the elbow, but dynamically it starts at the opposite cerebral cortex The hand specialty is not like palmistry, which stops at the wrist, but in a broad sense it should include the whole dynamic problem which affects the use of the hand The nerves of the brachial plexus and of the arm are mostly hand nerves, the hand is dependent directly upon them Since the hand is in fact the important part of the arm, the object of the arm is to innervate and support the hand As Rowley Bristow has stated The surgery of the upper extremity is the surgery of the hand"

The best results in our Army were not obtained by passing hand surgery from one tissue specialist to another The best results were obtained when one man alone, dealing with the problem as a whole, attended to these three aspects. The skin covering was then applied with consideration of hand movements, of deep structures, and of future procedures that could be known only to the one responsible for the whole problem Although hand surgery probably consists more of orthopaedic surgery than of plastic surgery or neurosurgery, the nerves should be repaired when the hand and forearm have been dissected and lie open instead of necessitating double surgery The British custom of including peripheral nerve surgery in orthopaedic surgery works well, as the neuromuscular aspect is of course, one problem.

Some points of progress in the reconstruction of hands in the Army may be of interest All the knowledge gained was pooled among the groups It was found that, if hands are kept moving they do not stiffen New covering was found to be best when made by abdominal flaps in two procedures, or, if the area was not suitable tube pedicles in one or two more steps were necessary There should be no raw surface, as this increases stiffening Free thick skin grafts sufficed for surface

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burns. Much bone carpentry was done the favored graft being cancellous bone from the ilium, fixation was accomplished by pinning Joints were moved to positions of function by elastic or spring splinting Proximal finger joints responded well to capsulectomy and arthroplasty Tendon grafts were used successfully when all the principles were adhered to Many tendon transfers were used, especially for radial palsy, to establish muscle balance in claw hand, to correct for loss of adduction or opposition of the thumb and to substitute for any or all of the intrinsic muscles

Repair of nerves within the hand gave good results, as did also nerve grafts of small diameter For nerve lesions high in the arm, there was need for collaboration of treatment by one versed in hand reconstruction to keep the hand in the position of function, to keep the joints and tendons moving, and eventually to transfer tendons. Occupational therapy proved to be of far more value than physiotherapy although the latter was needed for repair of nerve lesions Many cases of causalgia were cured by preganglionic neurectomy, and by the use of this procedure, other trophic conditions were improved. There were many reconstructions of digits to give prehension, and in these the importance of nerve supply and motion were recognized Thumb posts were useful if made short and thick, and phalangization and osteotomy were also used extensively Pollicization of a functioning index finger from the same hand, with its nerves and blood vessels intact, proved to be very successful.

Last June, I went to England to see what they were doing in hand surgery Brigadier Furlong, of London, had previously come here for a similar purpose, and had carried back with him what we had to offer He is now the consultant for hands in the British Army and I hope he will succeed in making hand surgery an entity in the British Army Quite a few men in England are interested in hand reconstruction. Excellent recovering after burns and the making of webs are done at their four plastic centers, the plastic surgeons being the ones most interested in hands. I think they have hand cases there with worse burns that we have Cuthbert reconstructed new thumbs even grafting a joint into one. Seddon was grafting a ring finger from the opposite hand for a thumb Pulvertaft showed a dozen excellent results from grafting a flexor tendon plus a paratenon into a finger, using the removable-wire technique. He and Furlong are attempting to form a British society for surgery of the hand, such as ours. Among those interested are Gillies, McIndoe, Molem, Kilner, Barron, and Moore. Let us hope that they will succeed.

Meanwhile, let us make our own Society grow in its important work. I am sure that the day will come when there will be in the various nations many active reciprocating societies for surgery of the hand

AMPUTATIONS

Amputations done during infection, following injury, or later as elective differ in indications, formation of flaps, and level.

During Infections

Here the aim is to rid the offending part of the member, to open the least amount of tissue, and to give the best drainage. The guillotine operation has proved its value. Skin, fascia and muscle are circumscribed in turn and allowed to contract. The bones are severed at the bottom of the cone Drainage is wide open. Excess of vascular ligamentous tissue and tendon ends are cut off, and if at a joint, the articular cartilage is shaved away as these structures lead to long sloughing The skin is drawn over the end by traction during healing When healed and clean, a secondary, careful operation is done. In the old and arthritic cases it is better to amputate a badly infected finger than to retain it and thereby cripple the whole hand by stiff joints. This applies especially to the ring finger which is the one that holds back most the movements of the others in flexion and in extension.

Following Injury

If too much is damaged to be worth reconstructing or the circumstances are such that expense and time of reconstruction would be impossible, amputation is a quick solution. This is preferable to long treat

ment for drainage and infection and having a stiff finger as the result Usually, how ever, it is best to err on the conservative side and save every tab of skin that might make a useful covering later In amputat ing a finger in a hand with a cicatrix it is well to bone or fillet it and save all avail able skin with its vessels and nerves to lay over a defect in the hand Though for a finger it might eventually be best to ampu tate back through the metacarpal or wrist joint to make a better stump, one should not do it as a primary operation for fear of carrying infection higher Thus primary amputations may not be perfect, but are preparatory to secondary ideal operations later The surgeon should use any skin that is available, rather than conform to an orthodox type of amputation Should the bone project beyond the skin the length of the digit may be preserved by raising a flap from the abdomen to cover the stump This is preferable to embedding the stump in giv ing better vitality of the pedicle when it is detached. Penicillin should be used as in all pedicles for primary closure Amputated finger tips may be covered by thick split grafts or a pedicle from the thenar emi nence, but a pedicle from the opposite side of the trunk, either high or low, is prefer able Amputated finger tips may be cov ered at once by a free thick skin graft or by a pedicle graft. For stereognosis, skin with rugae and special touch corpuscles should be used, as a free graft from a toe If small even some pulp can be carried with it. It is better though more elaborate to use for stereognosis a pedicle graft from the thenar eminence, the ulnar border of the other hand, or a toe. Abdominal skin will not acquire good stereognosis Kutler sug gested to incise from the cut end of the digit a triangle of skin on each side leaving each attached to the pulp these being thus mobi lized can be sutured together over the end of the digit and the two side slits in the digit closed

General Principles of Amputations Distal to Forearm

Indications Amputations in the upper limb compared to the lower should be con servative. The thumb merits ultra-conserv atism, preserving what remains if there is any hope of reconstruction

Any possible material in the hand should be salvaged for later reconstruction of op-posable prehensile digits A trident or lob-ster claw hand, if digits can be opposed or squeezed together in grasp, means much to a patient

In general, conserve all possible, as the reconstruction can be figured and carried out later Even the skin of a finger that is otherwise useless may be used to cover a defect in the hand so it should be saved intact with its nerves and vessels

If, after considering the above, too much is damaged in a finger to make it worth reconstructing, such as tendons, nerves, and joints, it is better to amputate and spare the long siege of healing, the stiffening of the hand entailed, and the final stiff, use-less finger which will always be in the way We should not amputate for merely an open fracture, a severed tendon, or severed nerve, for any one or even two of these can be remedied, but if there are several such injuries (tendons, bones, joints, nerves, skin) amputation is justified If a bone be fractured the amputation need not be done through the fracture for the fractured ends can be made to unite. It is the soft parts that limit the length of an amputation stump It is best to save redundant soft parts and build out the bone later A stiff finger is in the way and is better ampu tated If there is a painful middle joint, a useful digit may be made by excising it and ankylosing the adjoining phalanges, mak ing a shorter finger in the position of semi flexion It will be more useful than in the way If a finger is stiff it is useful if flexed and short.

In children we should follow the conservative course because of their great power of regeneration In women and men of sedentary habits the digits should, if possible, be saved for cosmetic reasons, but for a manual worker utilitarian reasons prevail If some digits are already missing, greater conservatism should be shown the remaining ones.

Whenever several digits have been amputated, the remaining few digits should be given greater strength by transferring to their tendons the spare tendons in the forearm which formerly controlled the fingers which were amputated.

Shaping Skin Flaps In the primary operation at the time of injury it is usually best to save all possible viable skin flaps and even the skin of a digit which is being amputated. In a hand we rarely have the opportunity of making special amputations, but instead must use whatever skin is available whether volar, lateral or dorsal As a rule volar skin is the best from the standpoint of wear and special tactile sense organs Where possible, it is best to make a long volar skin flap and a short dorsal one. Muscle tissue for flaps is absent in digits Our aim is to maintain as much length of the digit as possible providing it will have a good workable end In proximal finger joint amputation, usually a racket-shaped incision is used. For amputations in the hand or digits the scar should be terminal or dorsal, and it is better for it not to be on the tactile surface. In the forearm and arm equal flaps are used and the stump should be tapered not bulbous.

Special Tissues in Amputations. In amputating through the base of the nail, every bit of nail forming matrix including the tissue directly beneath the nail should be removed to prevent growth of a horn In amputating through a finger joint, it is well to shave away the cartilage to give a stump with less mobility at its end. The head of a phalanx is wide and bulbous for cosmetic reasons it should be narrowed. In amputating a finger, the flexor and extensor tendons should be severed and allowed to retract. They should never be sutured across the stump or they will limit flexion and extension of the other fingers. The short stump limits the excursion of the tendon so the other tendons from a common muscle and with their interdigitations can not have full excursion either When, however, an amputation is done through the limb proximal to where the limb is interdigitated, such as at the carpus, the tendons should be united over the end of the stump to furnish wrist movement Nerve ends in stumps often grow sensitive neuromata in three months If they happen to be just beneath the skin, a raised hypersensitive whorl will form on the stump Painful amputation stumps are common especially of such sense organs as fingers. Some people show special tendency to reform neuromata. Many finger stumps are painful and tender because of cicatricial tissue. One that has been infected, or has for a longer time been covered by granulation tissue before it finally heals over, is especially apt to be painful Usually in these cases, and after fingers have been crushed it is necessary to reamputate liberally far enough back to be through good tissue. In the late war there were very few painful neuromata in the Army because, after the primary guillotine operation, a secondary amputation was done through clean tissues It is infection that leads to scar causing painful neuromata For painful amputation stumps and treatment of nerve ends see page 375

Preferable Levels. Within a finger amputations should yield as long a digit as is possible providing that it has a good workable end A nonsensitive, durable end should in a finger, take preference over length, though it is often possible to maintain the length by adding skin and subcutaneous tissue by the pedicle method. A finger may be amput... through any of its joints, as, unlik... putations, there

is no need to fit a prosthesis Even if only the stub of a finger is left it will be useful in checking objects from falling out of the palm The middle joint of a finger adds to the grip

Amputations through a proximal finger joint have much in their favor Preservation of the metacarpal head insures a firm, broad palm for grasp and good leverage transversely The integrity of a strong metacarpal arch is preserved In one who works, the metacarpal head should be preserved. In those in whom cosmetics over value working ability, as in some women and sedentary men, a good result for them will be achieved by removing the whole metacarpal, except for the base where the extensors of the wrist attach, and then narrowing the hand In the case of the index or little finger, a volar flap is drawn around and sutured to the dorsal skin of the hand with excellent appearance Many surgeons believe that this is preferable even in a working man than to have an index stump off through the middle or proximal joint. They claim that such a stump prevents the long finger from gaining dexterity in taking the place of the index and that an index stump catches as on entering the pocket. If the metacarpal removed happens to be a central one (long or ring finger) the marginal ray whether index or little, should be jogged over by osteotomy at the base to take its place This narrows the hand and braces the adjoining metacarpal heads together to prevent rotation

If the head of a central metacarpal be lost, the adjoining metacarpal heads will so roll toward each other that their fingers will cross on flexion The remedy is to excise the metacarpal at its base and narrow the hand as just stated. If the head of a marginal metacarpal index or little is lost, even in one who works that metacarpal should be removed obliquely at its base A narrow hand with one finger missing is scarcely noticeable as people rarely count fingers.

FIG 539A Prosthesis for a hand amputated across the carpus but sparing thumb Partially flexed fingers against which thumb works are of metal A glove may be worn

When the heads of both the ring and long metacarpals are gone, the little finger will rotate towards the thumb This will be to advantage in approximating the thumb and the little finger If, though, the little finger is present, and, also, the head of the ring metacarpal, then a rotary angulatory osteotomy of the base of the fifth metacarpal will allow the little finger to work against the thumb without strain.

An amputation through the distal ends of all the metacarpals will give a useful hand with the aid of either a simple prosthesis or a phalangization operation which provides two or three short opposing digits

An amputation through the metacarpals, carpometacarpal or intercarpal joints gives a useful limb even without a prosthesis. If the amputation is at the carpus, the tendons should be fastened together across its end for strong wrist motion giving a useful, movable stump at the end of the forearm Unlike a prosthesis it has natural feeling It does not fit any standard limb socket, but such a stub may work against a flat hook from a forearm cuff or a split hook may be fitted to it with a hinge at the wrist. This prosthesis is stable on the arm without attachment above the elbow, and with wrist movement hinged in one plane there is the advantage that the hand can point It is quite possible that the motion of the wrist will eventually be utilized to activate prehensile fingers

If, in addition, the thumb remains, good

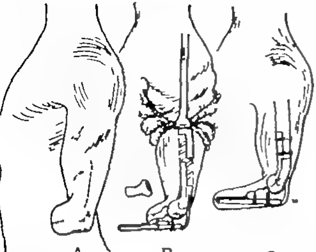


Fig. 539B Method of converting a below-elbow stump that is too short (i.e., less than 1½ inches below the biceps tendon) into one that is long enough to wear a prosthesis and has sensation.

(A) Incision around stump and up each side.

(B) The skin is peeled back like a sleeve, and the humerus is shortened. The head of radius is removed and the ulna is elongated by bone graft. Biceps and triceps tendons are *shortened*.

(C) Skin sleeve now relatively long is pulled down and sutured over the end of the stump It conveys normal sensation for wear thus avoiding resorting to pedicle skin graft.

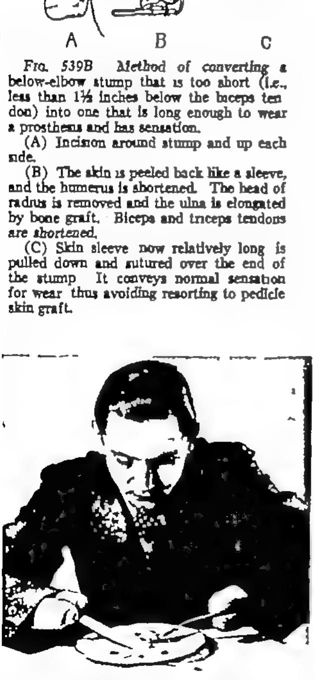


Fig. 539C. Krukenberg amputation-plasty The great advantage is that prehension and the sense of touch are preserved. (*Courtesy of G F Neubauer*)

use is made of a prosthesis consisting of a clawed metal hand fastened solidly to a metal and leather forearm piece. The thumb will work against it. If it is a finger instead of a thumb that is the lone survivor, a *similar* prosthesis can be placed opposite it.

Higher Amputations

The loss of an upper extremity is far worse than that of a lower extremity and fortunately happens less than one-fourth as often (20 per cent in war surgery) The hand is the important part of an arm. If lost, the handicap is great. At the best, an insensitive, artificial arm has very limited value and its whole purpose is merely to be a substitute for a hand.

Radiocarpal Amputations The past unpopularity of radiocarpal amputations was based on poor circulation, prominence of the ulnar styloid, pain in the radioulnar joint and the fact that the cuff must be so tight that supination and pronation were interfered with Some have been very satisfactory Covered in part by palmar skin they had circulation The flare of the wrist aided in retaining the prosthesis, thus eliminating an arm cuff An advantage is in a large range of the motion of pronation and supination. The hook, which extends a little longer than in a forearm amputation, *can be opened behind the back* and above the head. The presence of even a little of the carpus is very advantageous in rounding out the stump and stabilizing the radio-ulnar joint Retention of two rows of carpal bones is still better

Forearm Amputations. Amputations through the forearm are unsatisfactory in the lower third because of poor circulation and of lack of muscle padding The level of election is between the middle and lower thirds Here some ability to pronate and supinate is preserved The muscles are cut off at the level of the amputation but the fascial flaps are left long to overlap over the

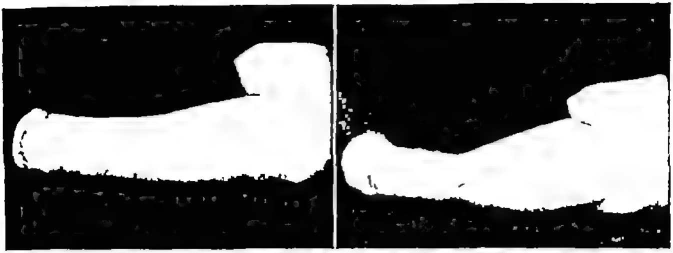


FIG. 540. Amputation through carpus (A *Left*) Pronation. (B *Right*) Supination. This is much better than an amputation through the radiocarpal joint

ends of the bones This gives a narrow, conical stump, with good circulation, that is well adapted to a prosthesis. Shorter forearm stumps should be made thinner and firmer by excising muscle so the prostheses will grip them firmly Some advantage is gained by transferring the biceps insertion to the coronoid process and excising the head of the radius The upper level of usefulness is a stump 1½ inches below the biceps A little longer stump is far better for there should be two or three inches of clearance in front of the elbow for flexion. In very short stumps a very close fitting bucket gives slight but unsatisfactory control. The alternatives are amputation above the elbow or the following.

Elongating Short Forearm Stump for Prosthesis. There is a tremendous advantage in an amputation through the forearm over one through the upper arm The latter needs constant setting at the elbow by the other hand and there is much lack of control. It is well worth while to elongate the forearm stump if a forearm prosthesis can be used instead of one for the upper arm

One method of building out by pedicle skin graft and bone graft is shown in Fig 541 The disadvantage is that soft parts furnished by the pedicle method are insensitive and require a year to gain sensation to pin prick. Without acquiring the protection of sensation they wear on the prosthesis, a trophic ulcer forms and deepens to the bone graft Pedicle skin grafts on weight bearing stumps have given much trouble. In the upper extremity, however, if the use of a prosthesis is delayed until sensation from a pin prick returns throughout, they should succeed In amputation stumps in general, better than a pedicle skin graft is to have a termination of natural skin with its normal nerve supply If, in the stump the bone projects, a pedicle skin graft must be used, if length is to be maintained If, however, the soft parts are redundant, it is entirely practical to build out the bone to fill them

Operation for Elongating Short Forearm Stump It is the soft parts that limit the length of an amputation stump The bone may always be elongated Our problem is to elongate the soft parts with their normal protective nerve supply and at the same time elongate the ulna by a bone graft I suggest the following Through a terminal incision along the scar across the stump and running up the outer side, the skin and subcutaneous tissue are separated from the deep fascia to above the elbow and about seven inches up the arm. The humerus is then shortened enough and rejoined by screws or plate. The cylinder of skin is drawn down the arm It then

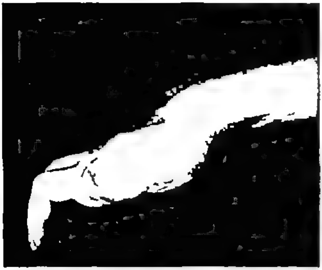
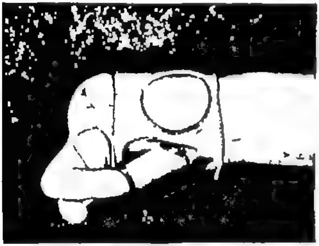


FIG. 543A and B Amputation of radial part of hand with prosthesis substituting for thumb (Courtesy of L. D Howard, Lt. Col., M.C. Wakeman General Hospital.)



Tactile skin is placed over the two contact surfaces, that is in the bite, the two incisions being made one well ulnarward on the dorsum and the other somewhat radially along the volar surface One jaw, the radial is covered completely with normal skin, but the deficit of the ulnar jaw is covered at once by an abdominal pedicle flap of skin, a strip of normal skin with mainly the internal cutaneous nerve suppl being left over the biting surface of th jaw The muscles and interosseus membrane are carefully separated high until the bones spread widely to 5 inches between their ends. The radius spreads from the ulna b biceps, extensors of the wrist and the brachioradialis. These are left with the radius. The flexor carpi radialis and pronator teres are, also, left with the radius to help it squeeze against the ulna which it does with moderate strength. Muscles are not removed because the jaws must be vascularized to keep warm.

Though the result is not cosmetic, the patients are pleased. There is the ability to feel, and, also, if desired, a standard prosthesis may be worn. It is found not suitable for a minor arm as a patient will not use it, but it is suitable for an amputation of the major arm or for bilateral amputations. This operation is very popular in Germany where, in the Oscar Helene Heim, 700 have been done since 1938 The main indication is for one side in a double amputee, and for the blind who need to be able to feel They cannot manage a prosthesis because they cannot see.

The great advantage of the Krukenberg amputation over orthodox amputations with prostheses is that there is natural sensation. Therefore, the Krukenberg double amputee works better, faster, and more efficiently than does even the bilateral cineplasty amputee. Also, when desired for heavy work, a regular prosthesis with split hooks may be worn over the double stump

PROSTHESES

Artificial arms or parts of hands are too often discarded because of lack of sensation, for in the use of our hands sensation is equal in value to motion. In the dark they are useless. Leg prostheses are far more successful than arm. Be it ever so crippled, if a hand is painless, has sensation and opposing motion, or to 1 one. an hand for d lack takes to lity to intelli , and pe people skillful

and el

and do the work of a hand. It is not a natural, but a cultivated action It is not the hook that has the skill, but the man behind

In our Army special training in reconditioning is given all amputees so they will become skillful and well able to take care of themselves A test for graduation is placing them in a room where they are observed and having them perform all the specified procedures of ordinary living in a given time. Skillful double amputees are helpful in the training

The useful artificial arm is for amputations below the elbow, those for amputation above the elbow requiring more than the average skill and being quite limited in practical use are often discarded. This will change with improvements in prostheses An elbow control has been developed by the Navy in which a cable from the front and back of a shoulder harness passes, each in opposite directions, around the drum at the elbow As the arm moves forward at the shoulder the elbow straightens, and vice versa. This is a very natural motion The mechanical device for grasping like a hand is controlled by cords through guides or cables through metal sleeves running up the back of the elbow and to a harness about the opposite shoulder By shrugging the shoulder forward, the device opens, and on relaxing clasps firmly by a spring. The normal position of rotation should be semi prone and from this there is some controlled movement each way

Prostheses to substitute for hands are either in the shape of hands or else made entirely for practical use such as a metal split utility hook. The two hooks open by a shrug forward of the opposite shoulder, and close by a powerful rubber band They may have various projections for better grasp on the objects held. The Trautman and Dorrance types are particularly useful

The hook is interchangeable with the cosmetic hand, and, also in order to do special work, with many types of devices such as

FIG. 543C Prosthesis for use when only the thumb remains. Devised by patient. Allows writing grasping firmly of large and small objects and looping the ring over objects. (Courtesy George S Phalen, *O Reilly General Hospital.*)

a vise, chuck, grab hook or various tools It is an English custom for the amputee to carry these around in a well arranged tool kit.

Cosmetic hands that look more or less like hands, and over which a glove can be worn, are less useful Some have malleable digits that can be placed in any position Many have joints, from one to three, in each digit. Either the thumb or the fingers move, controlled by sleeve cables from the opposite shoulder Fingers are generally made parallel to each other to present a flat surface for the thumb or may be made to give a three point grasp In some the last two fingers may be set in any position and the first two can be worked against the thumb (Hüfner) Hands are of wood, metal or plastic material Some have a whiffle-tree arrangement to equalize the force of the digits Others move by levers chains over pulleys or worm screws and one has a force amplifier of 5 1 which works automatically to fit the need in grasping

Various prostheses may, by the other hand be placed and set in several or any positions This includes a swivel table above the elbow for rotation, an adjustment to set the elbow at any angle, and one to

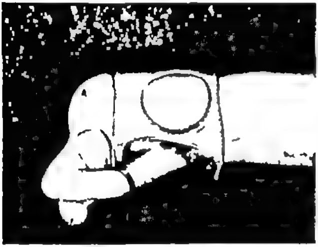


FIG. 543A and B Amputation of radial part of hand with prosthesis substituting for thumb (Courtesy of L. D Howard, Lt. Col., M.C., Wakeman General Hospital.)

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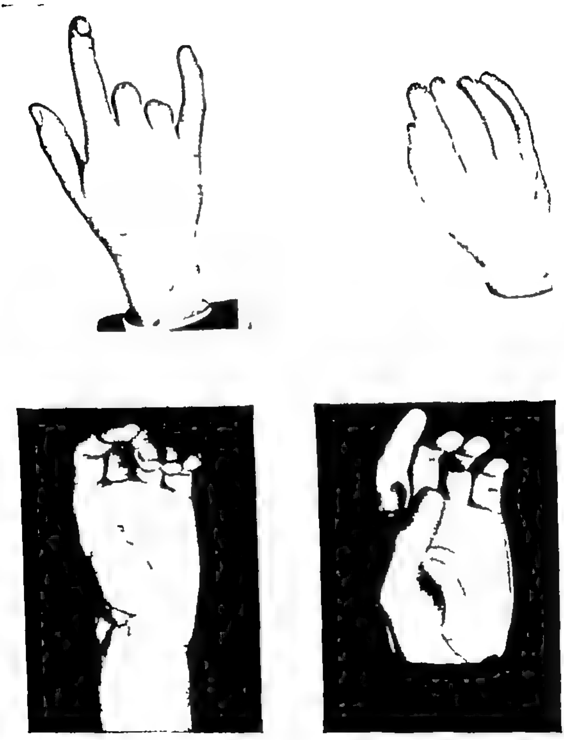
PLATE 5

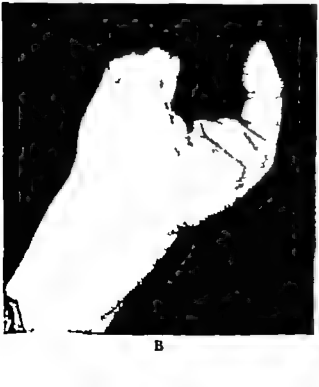


Lifelike plastic prostheses used for cosmetic purposes in cases of defects of part or a whole of hands made of high heat Vinyl Resin with pigments to any tint of color laid in before processing (Courtesy of L. W Harris, D D S Naval Dental School, Bethesda, Md.)

A

C

FIG. 544 (A, *Left top*) Partial amputation of hand. (B *Left bottom*) Revision of stump by pedicle graft. (C, *Right*) Prosthesis devised by patient. When movable utility hooks are detached, the thumb works against leather stump cover (Courtesy of L. D Howard, Lt. Col., M.C., Wakeman General Hospital.)



B

set the wrist for any angulation or rotation in pronation or supination. Also, digits may be set in various positions where they will maintain their grasp

With the usual forearm amputation, pronation and supination are slight. A prosthesis (Northrop) recently developed increases this motion two and one-half times by gearing up, and by a free-wheeling device makes the motion easily controlled by the stump but not at all by the object held in the hook. A prosthetic hand made for a wrist amputation (Port) successfully opened on supination and closed on pronation. For this a double bar brace hinged at the elbow extended to the axilla.

A man who has lost one arm will compensate by developing the use of his good arm, becoming left handed if the right is gone. If ambitious, much pride develops in these accomplishments, and if the amputation has been done in childhood the skill may be astonishing With the development of compensatory ability there is a tendency to discard the prosthesis.

In amputations through the hand, if there are two remaining digits that can feel and

work against each other in a prehensile way, no prosthesis will be used. If, though there be but one remaining digit, a prosthesis will furnish the necessary broad hook with flat surface to work against. This is especially useful if the thumb remains and the fingers are off at the base of the palm. By a metal and leather cuff laced on the forearm, semiflexed metal fingers are held so the thumb can work against them. If only the thumb is off, the patient usually discards the prosthesis furnished him. In contrast, a new digit produced by reconstruction or phalangization will be most useful. For an amputation through metacarpals or carpals the split utility hook may be used with the hinge action at the wrist. It projects lower than it should but is useful. When a man has a partial hand with a little useful but weak prehension by a few digits, a prosthesis may be fitted onto what remains of the hand to make it possible to perform heavy work.

Just now research is being carried out especially by the Committee on Prosthetic Devices, National Research Council, financed by the U. S. A., composed of both engineers and surgeons to improve prostheses. Some of the new developments are the Northrop arm, the automatic elbow, a system to have sensation in hand movements, and a power-driven automatic arm. With the aid of the engineering profession there should be progress. Ideas impractical at first, may sometimes bear fruit. To appreciate sensation in a prosthesis, a fluid bulb over the pulp of each finger connects by tubes to under each toe. The motions of the hand are then hydraulically driven by motions of the ankle. The automatic arm is powered by a battery and motor, matchbox in size, in the axilla and has motions in six joints directed by buttons on the chest!

Beautiful imitations of hands have been made of vinyl chloride as a hollow glove ⅛ inch thick. The texture, coloring and translucency are close to perfect. They fit on an amputated stump or onto a partial hand when part of the hand is missing. The fingers may contain malleable metal to be set in any position desired. Experiments are under way to furnish a movable core for each digit.

Cineplastic Amputations

In 1898 Vanghetti, who was not a surgeon, conceived the plan of using the muscles in the stump to activate the hand and Ceci, a surgeon, applied it. In the leg it was not suitable as there stabilization instead of movement is more important. In the succeeding years the method was advanced in Italy by Codivilla, Galeazzo, Pellegrini and Putti. During the First World War Sauerbruch in Germany improved the method and later Bocchi Arana in Argentina contributed a modification. In this country Kessler, using the method of Sauerbruch, has had such success that of his 78 cases he found that at the end of from two to six years 44 used their prostheses and 34 did so part of the time. This, he states, is a greater proportion than used their orthodox artificial limbs, and especially in upper arm amputations, claiming that in a survey in this country of 276 cases only 12 per cent used them and in one in Germany of 7000 cases only 1.8 per cent used them. In a personal observation, a forearm amputee who had a cineplasty on one side, his major, and an orthodox hook on the other, used the latter so much more that this became the major hand. He then had the tunnels removed.

Main muscle groups were used as motors: for the upper arm, the biceps and long head of the triceps; for the lower arm, the flexors and extensors. Various plastic attachments for the muscles have been used such as terminal loops or clubs, but later, the short, skin lined canal through the muscle was adopted. There was much ulceration and necrosis until a satisfactory technic was developed. One advantage of cineplasty is that movements are natural, the opposing

Flexible hollow prosthesis of polyvinyl chloride with finger cores of malleable copper Method of making was learned in the Army Prosthetic Research Program. (Courtesy of C. O Anderson, ceramist, San Francisco.)

work against each other in a prehensile way, no prosthesis will be used. If, though, there be but one remaining digit a prosthesis will furnish the necessary broad hook with flat surface to work against. This is especially useful if the thumb remains and the fingers are off at the base of the palm. By a metal and leather cuff laced on the forearm semiflexed metal fingers are held so the thumb can work against them. If only the thumb is off, the patient usually discards the prosthesis furnished him. In contrast, a new digit produced by reconstruction or phalangization will be most useful. For an amputation through metacarpals or carpals the split utility hook may be used with the hinge action at the wrist. It projects lower than it should, but is useful. When a man has a partial hand with a little useful but weak prehension by a few digits, a prosthesis may be fitted onto what remains of the hand to make it possible to perform heavy work.

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FIG. 545 Burn casualty returned late from overseas, treated by bone toilet and split skin grafts Pedicle to be applied later (Courtesy of Truman Blocker Col., M C., Wakeman General Hospital.)

muscles being balanced in tone and movement developing skill, and by muscle sense a conception of position the size of objects, and the right strength of grasp Each muscle by an ivory peg pulls on the opposite arm of the lever, which is balanced by adjusting the attachments along the lever arms. This, in turn, opens and closes the hand. Another advantage over the usual artificial arm is that the apparatus in a forearm stump is lighter and shorter, not extending above the elbow except for a strap which loops about the upper arm above the elbow For upper-arm prosthesis the strap fastens to the opposite shoulder Important disadvantages are that the motion is weak and the amplitude too small to be practical for other than but very light usage.

Not having had personal experience in cineplasty, the following is condensed from Nissen and Bergmann, who worked in Sauerbruch's clinic until 1933, and had subsequent experiences in this line. Cineplasty is not adapted to those who do heavy labor, but for those of a sedentary type who desire motion and skill even though it may be weak. They should have the mental equipment and perseverance to become adept These authors claim that cineplasty is successful in perhaps over 68 per cent of cases, which was the figure of Siegel in 1928.

Strength is proportional to cross-section area of muscle, a square centimeter lifting seven kilograms Work equals force plus length. A long muscle gives greater excursion and so is more adaptable than a short, thick muscle which has greater strength. A diagonal fibered muscle is not suitable. The excursion gained from a biceps is six centimeters and a triceps four A looped muscle pulls only 5 to 20 per cent of its normal strength and some of this is lost by friction of the prosthesis. In a short stump there is not sufficient excursion and in the lower third of a limb segment the tendinous parts are unsuitable so the favorable part for the canals is in the middle third of the upper or lower arm, *and preferably the* distal half of this and near the end of the stump A cone stump and perfect fit is desirable. If

the end is flabby with muscles, the bone can be elongated by a peg graft

A canal is made by raising transversely to the limb a flap of skin 4 or 5 cm. square with, for vascularity, its base to the radial side of the forearm and the medial side in the upper arm. The flap is tubed, skin side in, passed through the muscle, and sutured to the skin on the other side The suture line in the tube is placed proximal, away from wear The raw area in front of the muscle is closed by sliding skin or a free graft. The canal should be wide, short, and at a right angle to the limb If narrow it ulcerates It should penetrate the lower end of the muscle in a plane two-thirds of the muscle thickness from the bone. If the vitality is doubtful a two-pedicled flap is used, splitting and suturing the muscle over it.

The prosthesis for the forearm is a molded leather sleeve of two parts, joined by a collar ball-bearing joint to allow pronation and supination. If the stump is short, an adjustable swivel is placed at the wrist instead. Windows in the leather sleeve allow movements of the ivory pegs and stirrups and these, in turn by levers, rods, and rocking joints open and close the thumb and fingers.

In the upper-arm prostheses the muscles activate only the hand Pronation and supination are controlled through a swivel at the wrist by a cord over the shoulder and a locking screw, and motions of the elbow by a cord about the opposite shoulder crossing the scapula of the affected side, so a thrust forward of the stump flexes the elbow which can then be locked in position

The above was the status of cineplasty here until the Commission on Amputations and Prostheses, which was appointed by the Army and headed by Col Leonard T Peterson, reported after their tour through Europe in April, 1946 The Commission approved of cineplasty as now developed and, also, of the Krukenberg operation in selected cases The following is taken from their report

Cineplasty has so improved that it is extensively used in Germany, 7000 having been performed in Charite Krankenhaus Clinich in Berlin alone The meticulous methods of Prof Max Lebsche, who had done 500 cases, were particularly approved, the following being the improvements over the old type of cineplasty

Tunnels were made larger admitting a little finger and wore well with a 7 mm peg The flaps were made medial and the seams of the tubes were placed proximal In the forearm both tunnels were not made at the same time because of danger of necrosis Deep fascia was taken with the flaps and the muscle was covered over with skin graft. Tunnels were placed deep, there being two-thirds of the muscle superficial to them, and were placed in the lowest part of the muscle.

The lower end of the muscle was detached and sutured rolled in on itself

If a forearm stump were short, the biceps and triceps were used as motors In some the brachialis anticus would still flex the elbow, and in others supination and elbow flexion were done by shoulder cords and a spring was used for pronation The triceps was usually not detached. Its excursion was less, but enough In some a spring was used to extend the elbow A positive, double control was preferred. A tunnel in the flexor side of the forearm was used for retention of the prosthesis

If the upper arm stump were short, the pectoral muscle was used as a motor It had good excursion and four times the power needed.

Excursion of these motors was longer and with this the strength was greater Forearm muscles and triceps gave from 1½ to 2 cm. excursion and pulled 15 to 25 pounds Biceps and pectoral gave 5 to 7 cm. excursion and pulled 40 to 50 pounds.

Some of the prostheses held by retention loops without a shoulder harness. Amputa

tions above the elbow wore shoulder harness especially to work the elbow and pronation and supination while the biceps pectoral and triceps were used for the hand Below elbow prostheses had merely a loop around the upper arm. The wooden Hüfner hand was used uniformly It opened 5 cm

If the muscle is allowed to be contracted for long, it loses excursion and strength Therefore, exercises and tension should be started at once and continued. Long excursion is furnished only by long muscle and strength of pull is in proportion to the cross section of the muscle To have muscle length it is better to have the tunnel in the lower portion of the segment than in the upper As the muscle has its maximum strength only when under full tension (In man) the motivating part of its excursion should be in that range. For this an improvement in apparatus is necessary (For more details see Alldridge, bib)

BURNS

General Treatment

A burn involving the hand so often extends over a greater area of the body that something of the general treatment should be mentioned Death follows extensive burns and may be expected if much over one third of the body is affected the causal factors being as follows

There is first shock. This 48-hour period is overlapped by a period of toxemia in which there is depletion of water salt and protein from the constant weeping of exudate by such a large surface and also toxic absorption from the products of protein destruction As the period of incubation is reached infection is added, all of which are factors against the patient and those to be combated in the treatment.

Shock is treated by morphine, warmth whole blood or plasma, and oxygen by Boothby mask. For an extensive burn early transfusion lessens shock and acts prophylactically against hemoconcentration

Water, sodium chloride, and protein should be replaced as fast as lost by intravenous normal salt solution and plasma, frequent checks being made on the hemoconcentration to keep it down to normal, for the hemoglobin may reach 140 per cent. Enough plasma should be given to keep the blood protein up to 7 Gm per cent (determinations being made daily by the falling drop method) If the gram percentage falls below six, plasma escapes from the capillaries, causing edema and fluid loss by weeping. In burns of 10 per cent of the body surface 1000 cc. of plasma should be given at once before signs of shock appear, in burns of 20 per cent of the body, 2000 cc. Plasma is valuable in the first three days. One hundred cc. should be given for each hematocrit point over the normal of 45, or for each 100,000 in excess of the normal red cell count. Another guide is 50 cc. for each point in hemoglobin over 100 (Harkness) As infection supervenes on the third day contributing to the toxemia, whole blood preferable to plasma to combat anem hemolysis to keep the hematocrit to 40 an for hypoproteinemia.

In the first 48 hours plenty of normal salt solution is needed For less burned area than 10 per cent, 2000 cc. of normal salt solution is given and for over 10 per cent, 3000 to 8000 cc. and 3000 cc. daily thereafter to yield 1500 cc. of urine daily

Proteins are maintained by transfusions of blood, plasma, high caloric diet and amino acids Vitamins must be kept up. Chemotherapy, sulfadiazine by mouth and penicillin intramuscularly should be started early and maintained

The great factor of infection is best avoided by a primary clean up and maintaining asepsis, changing dressings at long intervals and under strict aseptic precautions gowns, masks etc.

It has been proved at the Birmingham Accident Hospital, in England (Colebrook and Glssane), that burns usually keep free from infection if all dressings are done in

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PLATE 7

Granulating area, exposed bone and joints after severe burn. (Courtesy of United States Army Medical Museum.)

FIG. 546 Granulations from burns were scraped off with handle of scalpel and skin grafts were applied under a pressure dressing (Courtesy of W B Macomber Lt. Col., M C., Dibble General Hospital)

a room in which an air purifier has been installed. They claim that most cross infections are airborne. Filtered, germ free air enters from the roof and leaves near the floor The bacterial count at any time is shown graphically in a revolving Petri dish against which the air is blown through a slit. The shake of a blanket makes a huge germ count, but even removing a dressing makes the count rise. The air of the room becomes repurified in five minutes.

Fluid loss from burned surface until recently, was combated by the eschar method

of Davidson which reduced the mortality to one-third, but this has given way to other methods, protective and pressure dressings and supplying for the losses of water, electrolyte, blood and protein

Various Methods In the past eschar methods were used tanning the wound surface by 5 to 10 per cent spray of tannic acid every half hour for 10 hours. Silver nitrate has been added Surface tissue that might otherwise have lived was damaged Necrosis of the liver was reported and in deep burns much infection occurred under the crust. Gentian violet and brilliant green in a 1 per cent spray was used, but this had similar objections The eschars by these methods formed constricting annular rings about fingers and even forearms causing gangrene. Eschar methods are not suitable for hands They have been abandoned

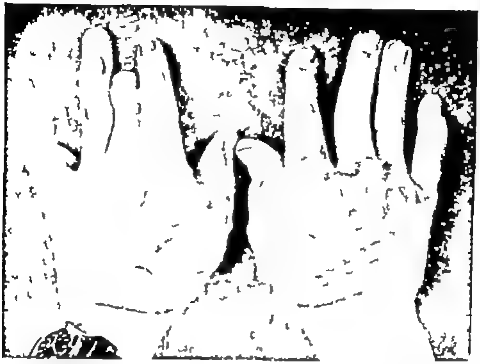

Fig. 547 Heavy keloid from over the dorsum of the hand following burn.

Local Treatment

In addition to saving life by combating shock, depletion, and infection, our aim should be to obtain the least scarring This is best minimized by avoiding tissue destruction from chemicals and from the bigger factor—infection. Thus, infection should be prevented and terminated early, so that the wound can be closed by skin grafting at the earliest time, before excessive and long lasting granulation piles up cicatrix.

In selecting from the numerous methods of treatment which have both advantages and disadvantages, the above main principles should be paramount in mind, choosing from our armamentarium whatever method is best adapted for the case and time. After discussing some of these various methods, certain aspects of treatment which apply especially to the hand will be mentioned.

Wax sprays were used to good advantage in first and second degree burns, but did not help in deep burns They formed an ideal surface under which epithelium spread

Bunyan Stannard envelopes have been used enclosing the hand and irrigating with a 1 20 solution of 1 per cent electrolytic hypochlorite three times daily alternating with external pressure Cleanliness was maintained by the antiseptic which, also, affects tissue. Exercise was encouraged.

Ointments have long been used Sulfonamide ointment has little or no effect locally, and too much of this drug may be absorbed With parenteral penicillin, penicillin in the ointment may be superfluous Ointments are messy and unclean They supply a smooth surface and do not adhere Fine meshed gauze or rayon accomplish the same and are cleaner

Baths of normal salt solution are valuable, used intermittently Hypertonic solution causes less weeping, but is too painful In them wounds may be cleaned, necrotic tissues cut away and toxins washed off Compresses have similar cleansing effect and are increasingly useful as slough separates. Normal salt solution is generally used and changed to hypochlorite solution for cleaning up Baths and compresses may be used intermittently with dry pressure dressings Penicillin is more effective with dry dressings.

It has been recommended to encase a burned hand in plaster of Paris for three weeks. The plaster must extend over a length of arm and the limb be kept elevated. It is claimed that the pressure prevents edema and infection The method is interesting but dangerous. I saw a terrific case of Volkmann's ischemic contracture that had been so treated

Routine Method For first aid it is better to cover with a sterile gauze dressing than with grease or other substance that will be difficult to remove.

Pain is controlled by morphine, keeping the burn covered with water by immersion or continuous stream, in a warm room, and if necessary by block or some general anesthesia.

The surrounding skin is scrubbed with soap and water, and grease is removed with benzine. The burn itself is gently mopped with soap and water and peroxide of hydrogen. All tabs of devitalized epithelium are clipped away Strict asepsis is used Débridement of full thickness of skin and immediate skin graft is rarely possible or advisable unless circumscribed and deep The burn is then sealed in, laying over it fine meshed gauze, 44 threads to the inch or better, rayon of 114 threads per inch * Neal Owens found that the latter is best One hundred and twenty threads to the inch prevented drainage and 108 allowed granulation to penetrate through the meshes To allow drainage it is applied wet and is kept moist If these are not available, petrolatum gauze, previously prepared in containers, may be used Then layers of gauze are placed in which are laid a few small catheters leading from the outside for instillations of normal salt solution Over all is placed plenty of cotton waste and a cellophane covering The whole is wrapped by an elastic cloth bandage so as to give firm pressure throughout and need not be disturbed for three weeks At that time the first and second degree burns will be found to have healed and the third degree may be ready for skin grafting (Neal Owens) On removing the rayon a beautiful smooth surface without bleeding is revealed. If the rayon should adhere, ether will loosen it The pressure keeps down edema, lessens fluid loss from weeping and leaves no pabulum filled space in which infection can develop Pressure dressings, as emphasized by Koch, are an essential feature in the treatment of burns and most wounds. Care should be used not to apply too much pressure as this may cause ischemic contracture of the hand. Penicillin is given intramuscularly

Many surgeons leave the first dressing in place only 10 days or two weeks Presence of fever and discomfort are indications to inspect the wound. Subsequent dressings are done with full aseptic precautions and at intervals of several days to a week At each dressing necrotic tissue is cut away If the wound becomes dirty, it may be compressed or bathed intermittently between the pressure dressings. Excessive sloughs

* Owen's surgical fabric is obtainable from Winchester Mills Inc., Hamilton Doherty Company 120 *West 42nd Street, New York 18*

FIG. 548. Showing the prevalent error toward conservatism in treating x ray burns as in this patient, a surgeon, in not making the pedicle grafts sufficiently large to include the borders of the burned area. These borders later had to be excised and covered with free skin grafts.

of the tendons and nerves slough from the hand and forearm from digits to muscles

The ideal treatment would be to excise the circumscribed tract, splitting the core by a longitudinal incision for inspection and removal and then closing In the usual procedure however, the burn is treated by tannic acid and later by wide drainage at the time of separation of the dead tissue and before infection is under way

Severe cases coming later for reconstruction present a formidable problem of flexion contracture and loss of many tendons and nerves, new pedicled skin and grafted in tendons and nerves usually being necessary One encounters inside the limb the same type of destruction and cicatrix as is found after any severe infection

Frostbite

From exposure to cold the digits, being peripheral and exposed, suffer from prolonged vasoconstriction as in Raynaud's phenomenon, and may finally freeze They then become painless, but on thawing out the pain is excruciating Frostbite varies in severity from first degree, with redness and swelling second degree with deep redness or cyanosis, swelling, blebs, and ulceration, to third degree, with gangrene. Thrombosis is a factor In those of second degree, the edematous swelling is progressive and blistering appears after several days to a week. There are hypesthesia and paresthesia, but in those of third degree, anesthesia When a frozen limb thaws, if still alive, the swelling and hyperemia are intense. After rapid thawing the gangrene is wet instead of dry Frostbite is prevented by wearing gloves with wool or fur insulation and an outside windbreak, and also when in the cold refraining from intoxication.

Treatment. The value of the old method of rubbing with snow to thaw very gradually is quite doubtful. Heat, however, should not be applied, for in the presence of impaired circulation it cannot be dissipated before cell damage is done. The patient is placed in a warm room and given a hot drink, and for vasodilatation, even alcohol. The frostbitten hands are warmed using not over body heat, and are gently rubbed and massaged to promote circulation, starting proximally and working distally They should be kept moderately cold to lessen metabolism. Fanning at 75 to 85° is advised Joints are moved passively and without force only as they loosen up, and then voluntarily Nupercaine ointment lessens the pain. After the hand is again warm, the subsequent treatment is the same as of a burn from heat. For the persistent sequelae, such as chilblains and poor circulation, good results from sympathectomy have been reported, but best results were gained by exercise and activity

Burns from Radiation

Physicians hands are often burned by roentgen ray in using the fluoroscope without glove protection in setting fractures and searching for foreign bodies, because the single or accumulated dosage is ex

ceeded Ten minutes at 3 milliamperes is the maximum exposure for one (Case) Sometimes, both physician and patient are similarly burned The location in hands is usually over the dorsum of the digits or like cancer This may show little or no tendency to heal after the erythematous stage is over

The stage of ischemia in burns from radiation follows that of erythema, and is

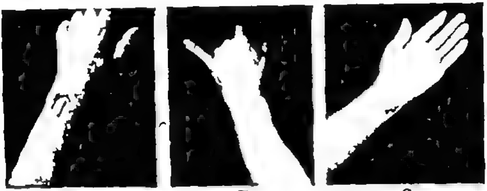

FIG. 549 Case W R. P X ray burn. A chip of steel entered the volar surface of forearm. This was removed under a fluoroscope the dorsal surface being toward the ray

(A) Gangrenous ulcer already a year old involving tendons.

(B) Ulcer was excised, covered at once temporarily with thin skin graft, and later with tubular pedicle graft.

Drop fingers were corrected later by tendon graft.

(C) A similar case of prolonged ulceration acquired in the same way

hand, or both or opposite the site of the foreign body

Burns from radiation are, by their severity, divided into three degrees

First degree—in from five to 14 days after exposure erythema appears, accompanied by a sensation of heat and itching This leaves in one to three weeks if it does not extend on to become a second-degree burn Later, from a month to two years, there may be loss of hair, dryness, and atrophy of the skin, with some telangiectasis

Second degree—the erythematous redness shows in five to ten days, and is soon followed by vesicles, edema, desquamation, or superficial ulceration These leave after a few weeks, to be followed by the stage of ischemia.

Third degree—this involves the thickness of the skin and deeper Following the first erythematous reaction, or even without it in the central part, there is necrosis and sloughing which is foul and smelly due to obliterative endarteritis and general sclerosis of the epidermis and subcutaneous tissue. Ulceration and sloughs may heal in the erythematous stage, but are indolent or stationary or may rebreak down in the later stage, when the redness turns to whiteness as the blood vessels shut down and the tissues are impoverished. When healing occurs the skin is poor and atrophic, with flattened papillae and loss of hair, nails, sweat, and sebaceous glands There may be pigmentation, keratosis, and troublesome crusts fissures and painful and tender ulceration rendering a surgeon s hand unfit for his work. Telangiectasis develops in the whitened areas as a compensatory hypertrophy of vessels If the burn were severe, deeper structures and joints will have suffered, so that covering of the bones will be thin and hard, and movement of joints will be limited. Finger joints may slough open and ultimately ankylose. Any additional exposure to the roentgen or ultraviolet rays should be avoided Exposure even to

FIG. 550 Double avulsion of bone fragment at insertion of extensor tendons, from stubbing the fingers. Can be held in place by one stainless-steel wire looped through the tendon about the piece and passed through phalanx and skin to be tied over a button on the pulp If not held firmly the bone absorbs.

ne actinic rays of the sun at high altitudes, r the infrared rays makes the condition orse. Malignancy, as a sequel, in the old evere burns is frequent, somewhere from 0 to 25 per cent of the cases so prophy ictic surgical removal in all is indicated. n "American Martyrs to Science," by ercy Brown 26 deaths from x ray burns re listed, 22 of which were due to cancer nd in three of which the cause was not nentioned

Treatment. A radiation burn seen early n the erythema stage shows much edema ous, red swelling and if severe an area of eep sloughing, with an indolent gray base nd cancer like odor Cleanliness with oric and later normal salt-solution com resses, in contrast to chemical ointments, ill clean up such an area and allow heal ng This stage of vascular swelling may st for a few weeks to two or three months, uring which time there is so much vascu rity that wounds will heal It is in the ter stage of avascular contracted cicatrix hen wounds will not heal For these, dry lfathiazole powder and immobilization ay result in healing New epidermis radually fills in under the crust. Occasion ally, if pus pockets form, eroding the sur rounding tissues, the wound should be cleaned up of crusts and débris The ulcer ated areas should be made to heal so they may be replaced by skin grafts, but the process is usually long and discouraging and the ulcer may never heal Aquaphor ointment has healed some. Healed skin must be kept soft by applying the animal fat lanolin and be guarded against injury

The only satisfactory treatment is to ex cise the whole injured area down to healthy tissue if possible, and to replace it by good skin It is hopeless to expect the damaged part ever again to metamorphose into good tissue If the atrophic skin is superficial and has a soft vascular base, it may be ex cised and replaced by a split skin graft of 020 inch in thickness. Whenever the atrophic tissue is deep or extensive, or bound down to the firm tissues beneath, it should be replaced by the pedicled skin graft containing subcutaneous tissue. A frequent error is to leave a border of slightly atrophic original skin about the pedicle graft, from not being sufficiently liberal in the replacement, as this border will continue to give more trouble.

In only the superficial radiation burns should free grafts be used If the bed is doubtful, only the thinnest grafts will take. Judgment should be used in selecting the thickest free graft which will take on that particular bed The graft should be applied immediately after the area is excised, with out waiting for a bed of granulations to spring up or else it may not take.

Indolent ulceration presents a problem. If it is first excised and then cleaned up by compresses of normal salt solution until covered by granulations and following that a thin skin graft is applied, the latter will probably break down in places. If, how ever, the skin graft .010 to 012 inch thick is applied immediately following excision of the clean granulations, it will be much more likely to take.

Fortunately, the result after excision and

replacement by good skin gives great satisfaction and relief from long suffering The whole hand improves in nutrition, due to liberation of the old contracting cicatrix.

Burns from Chemicals

Burns from the various acids or alkalis should at once be washed liberally with water, until there can be applied sodium bicarbonate to acid burns, and a very weak solution of acetic or citric acid to those from alkalis They are then treated as are other burns.

Carbolic acid, if strong, like other acids causes necrosis of the surface only, as it is quickly removed. Greater danger comes from compresses of from 1 to 5 per cent. Weak solutions concentrate from evaporation. The digit becomes anesthetic and in from four to 24 hours, from penetrating deeply, albumin is coagulated and vessels thrombose, causing necrosis. The finger is blanched or bluish white, at first with vesicles and finally black gangrene. Proximally, there is red swelling Carbolic ointment is dangerous to a lesser degree

RUPTURE OF TENDONS

General Aspects

When a normal tendon is subjected to excessive tension in the hand or elsewhere, the rupture occurs at the insertion by rupture of its fibers or by avulsion of a piece of bone at the musculotendinous juncture, in the belly of the muscle, or rarely at its origin Seldom does a tendon break from tension alone, except at its ends If a tendon becomes pathologic in part from direct trauma or disease, rupture occurs there even from slight strain Thus, if a tendon is crushed against the bone by a blow or a squeeze from a hard object, the part of the tendon injured goes through a stage of swelling and softening, as in tendon repair, and may break under even moderate strain in from one to four weeks. Tendon rupture

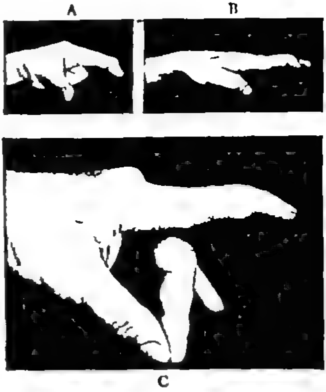

Fig. 551 Case J P

(A) Drop finger with defect of extensor tendon and extensive cicatrix to bone on dorsum from having been caught between a V belt and pulley

(B) The scar was excised and new skin was substituted by placing the finger under a ribbon of skin from the abdomen.

(C) A 1½ inch graft of thin layer from tendon of flexor carpi radialis was attached to the two lateral bands of the dorsal aponeurosis and to the distal phalanx, using removable stainless-steel wire. He regained good covering of the finger and the degree of extension shown

is frequent from tubercular tenosynovitis syphilis, the sclerosis of senility, from wearing on an arthritic or roughened bone, gonorrheal tenosynovitis and tumor

McMaster found that a tendon ruptures from tension only when cut half through but not when only one-fourth through nor did rupture occur after crushing or pounding until later Double ligation caused rupture under ordinary strain in from four to five weeks. This was not due entirely to loss of blood supply, but to tendon injury in addition as free tendon grafts are strong in four to five weeks.

In the hand, the ruptures encountered frequently are of the extensor aponeurosis

on the dorsum of the finger, because the extensor apparatus is so much weaker than the flexor tendon that it breaks under passive strain, and also of the extensor pollicis longus tendon at the wrist, where it is injured against the bone.

Rupture of Extensor at Distal Phalanx

If the finger, whether in active extension or not, is suddenly overflexed by a blow from a baseball, from catching in a door or from stubbing a finger as in making a bed, rupture of the posterior capsule of the joint occurs across the insertion of the extensor tendon, or less frequently a small piece of bone is avulsed from the distal phalanx. The rupture, though usually close to the insertion, may be more proximal over the middle phalanx.

Fig. 552 Fixation in plaster of Paris for rupture of insertion of extensor tendon from distal phalanx. Position with middle joint flexed and distal joint extended gives maximal relaxation to the tendon. The thumb holds the position while plaster sets.

It is found in both man and woman, but in a child the epiphysis may be avulsed. It occurs usually in the right hand and especially in the long finger, producing drop finger at the distal joint, or mallet finger. The middle joint may overextend in an effort to extend the distal one. The latter overflexes. The extensor tendon reunites, but is somewhat elongated, so the only voluntary extension present is in the position of flexion. Rarely an osteophyte grows, blocking extension. There is considerable complaint that the finger gets in the way and stubs in failing to clear objects in grasping, though less complaint from old cases who have learned how to avoid this.

Treatment. Conservative. A lateral roentgen view shows if bone has been avulsed. Conservative treatment, if commenced in the first week, restores perfect function, but if started in the second week

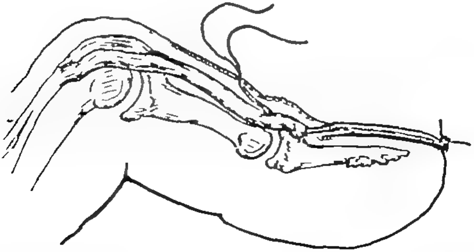

Fig. 553 Method of using stainless-steel wire for late repair of insertion of extensor tendon, fastening the suture wire to the fingernail and later removing it by the pull-out wire. (Courtesy Amer Jour Surg., 47 505 No 2 February 1940)

there may be some limitation of extension, and if started after two weeks limitation is expected The finger should not be splinted in the straight position on a tongue blade, but placed with the distal joint in hyper extension Also, the middle joint should be held in 60° of flexion to allow the two lat eral bands of the extensor aponeurosis to shift volarward and so gain 3 mm of slack Few splints will hold this position as well as plaster of Paris Godfrey's plastic splint is an exception (see Chapter 4) Plaster may be applied by Smillie's procedure A dry sheath of plaster of Paris bandage is slipped over the finger The thumb and finger are pinched together to maintain the above position, and after dipping the plaster in water are held so until the plaster sets. In order better to view the blood supply subsequently, the plaster instead may be laid in narrow, wet strips on the volar aspect of the finger, a cross strip added across the dorsum of the finger at its base and another just proximal to the distal joint. In the middle joint, moderate instead of extreme flexion should be used, as the joint is slow in again straightening If the finger is fat the plaster should include the hand After five weeks the splint may be replaced for a week by a dorsal half splint of collodion, made by painting three coats on the distal two segments in the position of hyperexten sion as improvised by Jelsma

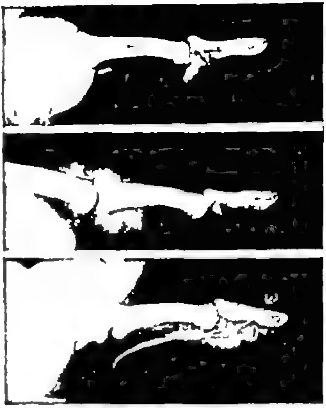

FIG. 554 Case F M T Avulsion of flexion profundus insertion in a surgeon from a fall on the finger with loss of voluntary flexion of the distal joint.

(*Top* and *Center*) Unfortunately the distal broken fragment had been removed. The end of the retracted profundus ten don is shown at the proximal flake of bone.

(*Bottom*) Operative repair Through a lateral incision the profundus end was drawn by a stainless-steel suture to the distal phalanx. The wires penetrated pha lanx and nail to be tied to a wire ring

Pull-out wire can be seen in place and also suture closing incision. Three months later he had 35 of voluntary flexion in the distal joint.

OPERATIVE. If too late for splinting, repair by suture is indicated. Exact technic is necessary or movement will be lost. The overlying skin is laid back by an L-shaped incision, crossing just proximal to the distal joint, and prolonged if necessary on up the side of the middle segment of the finger The blood supply of the matrix comes from the two sides. The skin and tendon are so thin that extremely delicate handling is necessary The reaction from rough han dling or from irritation by silk sutures produces adhesions to the head of the middle phalanx, which will prevent movement. There hair like No 35 removable stainless steel wire is selected to minimize the reac tion. It is spliced into the tendon, placing a pull-out wire for its removal, and is made to emerge through the skin and tie to the fingernail through a drill hole. The finger is put in the position just described for five weeks, but in three weeks the wire is withdrawn To lessen the reaction at the site of union, the wire can be attached to the tendon "at a distance," that is, more prox imally over the middle phalanx

Usually, at operation it will be found that the tendon has reunited, but is too long by 2 or 3 mm. and is adherent on the

dorsum of the head of the middle phalanx—especially if it has been cut. In some, the tendon can be shortened by cutting diagonally and overlapping, fastening by a movable running stainless steel wire, and in others merely freeing the tendon from its adhesions to the head of the middle phalanx and placing paratenon beneath and the joint in hyperextension will effect a cure. If a bone fragment has been avulsed, it is secured firmly in place by a loop of No 35 stainless steel wire about the piece, passed through a drill hole in the phalanx and on out the pulp, where it is tied over a bolster A pull-out wire is placed for its removal If not firm, nonunion or absorption of this piece results.

Buttonhole Rupture of Extensor Tendon at Middle Finger Joint

From sudden forced flexion, the middle slip of the tendon ruptures at its insertion at the base of the middle phalanx, or occasionally a small fragment of bone is avulsed In some the slip is cut, or due to a direct blow against the bone, the tendon parts at once or a week or two later As the middle joint goes into strong flexion, the two lateral bands as a secondary result tear apart, displacing volarward and allowing the joint to herniate through. The longitudinal tear or buttonhole is thus produced between them, running up one side of the central slip so the two lateral bands clasp the sides of the joint. The deformity is of flexion of the middle joint and hyperextension of the distal one. Any effort voluntarily to extend the middle joint merely overextends the distal one In some, a trigger finger action results As the middle joint half flexes the lateral bands suddenly snap to its side with a jerk and the finger cannot then be voluntarily extended As the joint is extended passively, the bands suddenly snap into place.

Treatment. *If seen within a week a* plaster splint is applied for five weeks, with wrist and proximal two finger joints in extension, the distal joint being left free. In a mild case without treatment, the deformity disappears in two years. In marked deformity or when seen after a week, the repair should be surgical. On uncovering the site through a longitudinal incision down one side and jogging to the other side across the rupture, the ruptured middle slip, which is part of the joint capsule, is united by a No 35 figure-of-eight stainless steel wire, which at the same time closes the skin incision In fresh cases the longitudinal tear repairs itself during the splinting, but in late cases its edges should be freshened and similarly united by a hairlike figure-of-eight stainless steel wire brought out through the skin. The extension splint is worn five weeks.

If the central slip has been destroyed the two lateral slips may be sutured together in the midline after severing the lateral sheath attachment. They will then extend the middle joint well, but not act as well on the distal joint. The latter can if necessary, be ankylosed in slight flexion Following burns it is rare that a tendon graft can be used to extend the middle finger joint because the cicatrix on the dorsum of the finger is usually too dense. If the dorsal skin is pliable, a method can be used described in Chapter 10

Rupture of Extensor Pollicis Longus

The tendon of the extensor pollicis longus, as it leaves the radius, runs through a bony groove capped over by the annular ligament. When the wrist is in dorsi and radial flexion, the tendon at this point works around a sharp angle, readily seen and felt in one's own hand, like the angle of the abductor pollicis longus where tenosynovitis occurs. It is uniformly at this angle that the tendon wears out on the *quite sharp bony edge and ruptures* in certain trades such as polishing, drumming

wood carving, carpentry, tailoring, etc. Here, too, the tendon frequently ruptures—not at the time of trauma, but following it. After a blow it may rupture while in the healing stage in one to three weeks, but after a Colles's or marginal fracture, due to wear on the malformed bone, it ruptures in three months on the average, as compiled by Kwedar and Mitchell in the 71 cases reported to 1940, however, it has occurred as early as one week and as late as ten years afterward. Only one, a partial rupture, occurred at once. There is loss of voluntary extension of the distal joint of the thumb and partial loss of extension in the proximal joint, so the thumb does not clear objects in grasping

Treatment. The tendon retracts almost two inches, so splinting alone is without avail Direct suture of the tendon ends is not possible, as there is a loss of a centimeter at each end by being swollen, frayed, soft, and yellowish. The distal end has been sutured into the tendon of the abductor pollicis longus, but this is unsatisfactory, as the tendon, having an excursion of only one-half, cannot give full range of motion to the thumb—nor does it cause the thumb to pinch against the side of the palm, as it draws in a radial instead of ulnar direction.

Excellent function can be restored, however, by either joining the tendon by a free tendon graft from the palmaris longus or by transferring its distal end to the tendon of the extensor indicis proprius. The stump of insertion of the latter must be fastened to the main index extensor to avoid malrotation of the index finger A cock up splint is applied to the wrist, with an extension arm to maintain the thumb in extension for a month.

Rupture of Flexor Tendons

Location of Ruptures Flexor tendons rupture less frequently than do extensors. The following cases from my files and from the literature show that the rupture may occur at different levels

At insertion—firecracker exploding in hand caused rupture of insertions of the profundus and sublimis tendons of both ring and little fingers Repaired late by tendon graft Good result.

Profundus yielded at its insertion as a handle was grasped to prevent falling

From fall on finger profundus avulsed with splinter of distal phalanx.

Two cases from pulling on objects.

Profundus ruptured at insertion in little finger while lifting table and coiled up in palm

The end of the long finger was caught in an automobile door and pulled upon, rupturing profundus tendon in its distal inch

Profundus insertion ruptured at a dorsal dislocation of the distal joint (Kanavel)

At middle segment of finger—profundus tendon of little finger ruptured as pommel was grasped on being thrown (Schlatter)

Rupture of one slip of sublimis tendon from grasping, resulting in trigger finger, at base of palm

A door was opened forcefully by the little finger in a knot hole. There was a 2½ inch gap in the profundus tendon. A good result was obtained by primary suture.

At base of long finger—from pulling on object.

At wrist (Thorne)

At musculotendinous juncture, tendons avulsed with wisp of muscle.

From an explosion in the hand (Edwards)

Distal segment of long finger caught in door and pulled off, including the profundus tendon (Adams)

Overextension of long finger in hitting a basketball drew the tendon out from muscle. Good function was restored by shortening the tendon.

Tendons and muscles avulsed—all fingers caught in machinery, avulsing with them most of the flexor tendons and muscles.

Muscles shot out through palm—arm drew in to elbow between a belt and a pulley, and on reversing the motion the palm burst and half of the flexor muscles shot out, hanging by their tendons Remarkably good function followed débridement and later transfers of some of flexor tendons

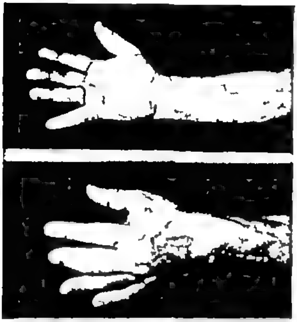

FIG. 555 Case C. P M., aged 57 Acquired hypertrophy of long finger from prolonged overuse as a tile setter and recent traumatic inflammatory reaction in peritendinous tissue. Even the radial and ulnar bursae were enlarged.

Through muscle belly—rupture here results from traction, at or following a direct blow on the muscle.

Flexor pollicis longus—ruptured in thenar eminence from grasping Ends were later repaired by suture.

Ruptured at forward angulation of Colles's fracture (McMaster who could find no similar case in the literature up to 1932)

LUXATION OF TENDONS

In the hand the tendon of the extensor carpi ulnaris in dislocations of the lower radio-ulnar joint, from rupture of a fascial sheet the continuation of the dorsal annular ligament, dislocates in pronation over the ulnar head as described under that dislocation. In the fingers when the middle slip of the extensor tendon is ruptured at the middle joint, the lateral bands subluxate volarward, as already described. Tendons bowstring or luxate out of their beds into the angle of flexion when their restraining pulleys or annular ligaments are not holding, as has been described under these structures. The remaining luxation to be considered is that of the extensor tendons of the finger slipping off from the convexities of the knuckles of the proximal finger joints, interfering with piano playing and other activities. These extensor tendons fairly frequently luxate ulnarward from over the proximal knuckles in flexion, especially in the long finger and often in the index. As the extensor tendon slips ulnarward from its position over the center of the knuckle, voluntary extension of the proximal joint is much limited and instead there is ulnar deviation of the finger Straus found that half of the cases were from direct trauma to the radial side of the dorsal capsule of the joint and half from muscular effort against resistance, either pathologically or from heredity As the knuckle flexes to 45°, the tendon jumps ulnarward Flexion can be completed, but not extension which stops at 45° With passive aid, the tendon slips back and the joint extends. In Becker's case, the extensor tendon split and the metacarpal head protruded between.

Normally, there is no lateral play of the extensor tendon over the proximal finger joint, as it is a part of the dorsal capsule or aponeurosis that is attached volarward to the sides of the proximal phalanx and *shifts distally and proximally for the gear* shift action of the intrinsic muscles. In cases of luxation there has been found, on the radial side, a tear parallel to the tendon and across the capsule and part of the tendon, so that the tendon no longer maintains its central position over the joint in flexion.

Ulnar tendon luxation is frequent in old cases of hypertrophic osteoarthritis with

the fingers, due to the effect of gravity, sharply inclining ulnarward in their proximal joints.

Treatment. Primary conservative treatment is only partially successful, operative repair being necessary The juncturae tendinum are not to blame—the lesion is in the aponeurosis of the tendon Several methods have been used Habernen turned over a transverse flap of fascia from the ulnar side of the capsule to the radial side Fitzgerald successfully grafted a strip of fascia lata across all of the tendons, suturing it with silk to each side of each and to the capsular ligament. In this case, the tendon of the ring finger dislocated radialward, while the other three tendons dislocated ulnarward, and there was a defect in the aponeurotic sleeve in that it did not reach as far proximal as the proximal joint

In several personal cases the tendon of the palmaris longus was threaded as a free graft through each extensor tendon, to each of which it was stitched and then fastened

FIG. 556 Case A. H. For two years there has been a painful swelling on the dorsum of the little finger At operation there was a soft homogeneous mass involving the dorsal aponeurosis and honey-combing the bone. The pathologist pronounced it tenosynovitis, fungus type.

into the far sides of the second and fifth metacarpal heads. It was also woven in passing through the sides of each capsular ligament for better fixation. In another nontraumatic case of a professional pianist the main extensor tendon was slit on each side from the dorsal aponeurotic sleeve of the proximal joint, and transplanted and sutured into a slit more radial in this sleeve These were all successful In several cases where a longitudinal rent in the radial side of the aponeurosis was sutured and where there was traumatic loss of the side of the capsule, tendinous slings were anchored to the side of the capsule or to the adjacent tendons, so as to hold the extensor tendon in place over the center of the knuckle. Sometimes the ulnar side of the aponeurosis had to be slit longitudinally to allow the replacement Whatever method is used we should include, when possible, an attachment to the side of the shifting dorsal aponeurosis, which in turn has on each side bony attachment to the base of the phalanx.

TRAUMATIC TENOSYNOVITIS

From trauma or overuse alone the tendons, muscles, and their surrounding tissues become inflamed Unaccustomed manual work entailing excessive use or overstrain of muscle and tendon, whether in a straight course or where they round a corner, causes crepitating tenosynovitis, and so can single, multiple, or oft repeated direct traumatism. In and near the hand, those tendons and muscles usually affected are the extensors of the digits and wrist, and over the dorsum of the carpus and lower forearm Less frequently, the long flexors or the tendons of the flexor and extensor carpi ulnaris and flexor carpi radialis are involved The tendon of the extensor ulnaris may be inflamed from rubbing over a malunited ulnar styloid. Traumatic tenosynovitis is common in the abductor pollicis longus and extensor pollicis brevis of the thumb, leading to stenosis, as described under de Quervain's disease, and local tendon and sheath thickening from trauma are seen in trigger finger and thumb

The gross pathology consists of edematous inflammatory swelling and petechiae

of the tendon, epitenon, tendon sheath, and paratenon This is greatest at the musculotendinous juncture, and the inflammatory reaction extends a way up into the muscle. In case of overstrain the muscle is the more affected, showing slight muscle tears and inflammation of the perimysium Microscopically, as demonstrated by Nelson Howard, deposits of fibrin masses are seen throughout the edematous paratenon and there is thrombosis of the venules In the muscles, also are fibrin deposits, and there is liquefaction necrosis of muscle fibers and of sarcolemma. The deposits of fibrin and the edematous folds of epitenon and synovia of the sheath account for the crepitation as they roll over each other From local trauma there is extravasation of blood in and about the tendon followed by inflammatory reaction. He explains the process as due to muscle fatigue the stored up glycogen being reduced to lactic acid This travels down the tendon, lowering the pH as determined by colorimetric hydrogen in concentration studies. The acidity causes edematous swelling The fibrin deposits are from the extracellular fluid which is rich in proteids.

An unusual form is that of "tenosynovitis fungosa," in which all of the extensor tendons and the annular ligament on the back of the wrist may be encased in a soft swelling which when uncovered shows a diffuse, fungus-like growth of reddish brown granulations growing over all of the tendons, imbedding them in a continuous jelly Some of the tendons are frayed, penetrated, and eventually destroyed. The appearance is that of tuberculosis though neither tubercles nor bacilli could be found. It is almost symptomless In a personal case it followed unaccustomed work in a garden and after surgical excision as in the two cases described by Howard, it did not recur

Symptoms of traumatic tenosynovitis are pain tenderness swelling and palpable and audible soft crepitation on movement of the tendons following by from one to several days the history of unaccustomed over use or trauma. Any strain or movement of the affected tendons, and especially if they are at the same time pressed upon, elicits pain If neglected the disability lasts for months, but if treated early it soon leaves.

Treatment. In mild cases the aching of the tendons and muscles may pass off as they acquire the ability to stand the unaccustomed use. Trainers in sports massage away the swelling and exudate, strap the part, and keep the limb active. After the initial increase of pain the patient can continue the activity

In a case of any severity, however, rest is indicated and activity aggravates. The limb should be immobilized so that all the affected tendons are relaxed and motionless. Pressure from the nonpadded, supporting cast removes the edema and exudate. Unaffected parts of the limb should be free to move, so as to maintain a healthy condition in the limb Howard's tabulations show that when well-splinted in a cast the disability averaged as short as 11 6 days compared to 22 6 when poorly splinted as on a board, and that when meddlesome physiotherapy was used the disability averaged 45 1 days.

Prolonged immobilization, without use of the unaffected parts of the limb, results in adhesions, causing continuance of pain and limitation of motion Therefore, after the initial immobilization of a week or two, the limb should be daily moved once through its complete range of motion to free the adhesions. Soon reactivity should be gradually increased as tolerated If crepitating tenosynovitis has become well established it may be necessary to immobilize for a much longer period

By routine aspirations and culture cases of gonorrheal tenosynovitis otherwise overlooked will be identified Tuberculosis should also be considered.

TRIGGER FINGER

The trigger phenomenon, or sudden snapping movement of a finger, may be from a number of causes flexor tendons slipping over each other in the forearm, the long extensor slipping on and off the proximal knuckle, two lateral bands slipping volar ward or back, from buttonhole rupture of the extensor tendon with each movement of the middle finger joint, and from a nodule in the flexer tendons catching at a constriction in the annular sheath opposite the metacarpal head.

The latter, which is the usual type, is from single or multiple direct trauma, usu ally incurred in grasping, and especially in the long and ring fingers. The ligamentous sheath and flexor tendon are pinched between the object and the head of the meta carpal until from local tenosynovitis a thickening forms in the sheath and a local swelling in the tendons.

When the finger is two-thirds flexed the motion is held up until, on more force, the nodule pulls through and the finger snaps into the palm in flexion A similar phenomenon occurs at the same place on ex tending the finger A tendon nodule moving with the tendon can be felt under the examining finger Finally, due to this increased irritation, the nodule no longer slips through the constriction and the finger is caught in either extension or flexion. If the distal joint is first extended the thick enings of the two tendons will then not coincide, thus allowing the tendons to slip through

Pathologically the ligamentous sheath shows a whitish, cicatricial collar like thickening In the tendons there is a fusi form enlargement at the bifurcation of the sublimis, mostly of the sublimis, though somewhat of the profundus, too The en largement is due to edema and inflamma tory proliferation of epitenon and a homog enous bluish, or yellowish expansion of the tendon from thickening of endotenon between the tendon bundles Some giant cells may be present.

Treatment. The condition, when new, subsides with rest, but otherwise is easily cured surgically Through a short, curved

FIG. 557 Case T G M Trigger finger trapped in flexion following gar dening. At operation the ligamentous sheath was found thickened and a fusi form swelling of the tendons was present where the sublimis straddled the profundus Simple lateral slitting through the annular ligament effected a cure.

incision in the palm embracing the nodule, the tendon and annular band are exposed and there, under the eye, the phenomenon is demonstrated With a tenotome the annular band is slit through laterally, never on its gliding volar surface, and is left so One or both sides may be cut from inside outward, taking care to avoid cutting the volar digital nerve.

It is impossible to excise any discrete nodule or to slice a wedge from the tendon, for a new lump would form as a reaction to any incision in the tendon itself Slitting the sheath alone will suffice From rupture of one or part of a slip of the sublimis tendon, a nodule may terminate the prox imal end, in which case it should not be excised locally as this would be followed by a similar nodule, but the ruptured end should be stripped up into the palm and cut off there where a new nodule will not give trouble.

A prompt cure is the rule, though one case in which the proximal joint habitually overextended before the finger flexed still gave slight crepitation as the mildly rough ened flexor tendons rounded the projecting head of the metacarpal.

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13

Injuries of the Hand Fractures and Dislocations

SPECIAL ASPECTS IN HAND
INJURIES OF WRIST
FRACTURES OF METACARPALS AND PHALANGES
DISLOCATIONS

SPECIAL ASPECTS IN HAND

In a case of what seems to be merely a sprain crush, or contusion we should be suspicious and take x ray pictures. They may show a chip or impacted fracture Clinical signs indicating fracture are local tenderness abnormal mobility either rotary angulatory, or to and fro, considerable swelling and ecchymosis, deformity, and pain on passive or active movements and on shoving up a digital ray

The main principles of treating fractures in general apply to those in the hand, and in addition there are some special aspects.

The bones of the hand are so vascular with the exception of the proximal end of the scaphoid that there is usually union in three weeks, nonunion being rare When it does occur it is due to separation or excessive movement. Even a metacarpal or phalanx may fail to unite if continual movement shears the binding fibers and young blood vessels trying to cross the gap, and instead causes the cells to grow parallel with the broken bone ends, sealing them in and preventing union.

Osteoporosis may become extreme throughout the hand due to hyperemia, a reflex from pain if the fracture is not immobilized. Lime cannot be laid down in the presence of hyperemia but instead is absorbed, and if infection is present the absorption is greater Therefore in hyperemia we find vacuolization of carpal bones and widening of fracture lines On immobilizing the injured part, combined with subsidence of infection and with use of the hand the bones will unite the apparent spaces between the bone ends and within the cysts filling with lime

Avoiding Stiffness. Following fractures the extensor or flexor tendons may adhere in the callus in wrist hand, or digits causing in the case of flexor tendons lack of voluntary flexion and of voluntary or passive extension, and in the case of extensors loss of voluntary extension and of voluntary and passive flexion This occurs much less frequently if the fracture is without displacement.

The mechanism of bones, joints, and tendons in the hand is so exact and nicely balanced that deformity from dislocation or malunion destroys both tendon leverage of the joints and muscle balance throughout the hand.

Posttraumatic stiffness in the hand is our big problem far more than after fracture or dislocation elsewhere in the body, because the mechanical parts are so intimately and compactly fitted together that any shortening of ligaments limits motion and because the long flexors and long extensors are practically each a common muscle to all of the digits, especially as regards flexor profundus and extensor communis digitorum One tendon held keeps the muscle from pulling on the adjoining ones If then we fix a finger in complete flexion or complete extension it will not only cause displacement of the fracture but

will hold back the other fingers from moving The position for fixation is of moderate flexion as in the position of function

Following a fracture, if we immobilize all the fingers together, they will all become stiff, whether strapped extended to a flat board or tied flexed over a bandage If the injured finger is immobilized to another the fracture will displace and both fingers will stiffen We should immobilize only the injured part or finger and leave the rest of the digits free to keep moving Thus, the injured part must be firmly enough immobilized so it will not move when the rest do Also, every other digit should be unrestricted in its whole range of motion and be made to move throughout the complete range repeatedly daily This may be done passively, but not voluntarily, because several tendons are attached to a common muscle and the tendons from the flexor profundus and extensor communis interdigitate Stiffness which is so readily prevented, is so difficult to cure (see Chap 7)

A plaster cast on a hand to immobilize a proximal or middle phalanx or a metacarpal must support the extension apparatus which holds the injured digit, and must grasp the hand and two-thirds of the forearm. It should, to hold firmly, be nonpadded for obvious reasons. The cast, wherever possible, should hold the wrist in 20° dorsiflexion, should conform to transverse arches of the hand, and should end on the dorsum at the knuckles In the palm it should not reach farther than the distal palmar crease so as to leave the proximal finger joints free to flex to a right angle, and should stop at the thenar crease to allow for opposition of the metacarpal of the thumb To make this the cast is completed in the palm by a fairly thick folded strip of plaster laid from the dorsum across the cleft of the thumb to fuse with the cast again in front. This bar is firm enough to wear, and passes fairly narrowly across between the thenar and distal palmar creases.

Such a cast leaves the hand free for the functional treatment of fractures, so ably described by Böhler Use of the hand is encouraged The more muscle and tendon action the better will be the circulation and nutrition and the freer the hand will be from adhesions of joints and tendons On removal we will have a mobile, healthy hand instead of what is commonly seen in the wrongly applied cast which includes all of the fingers, a useless one stiff, sore, and club-like and in position of nonfunction Such stiffness is often permanent.

It is a common error to put up a wrist in the straight position, for if in moderate dorsiflexion the muscles will be in balance with the hand in the position of function If the wrist is in flexion, the muscles are in balance only when the hand goes into the position of nonfunction.

A hand embedded in plaster to well down the digits, or at all beyond the distal, palmar and thenar creases, will stiffen, and when the hand is kept immobilized in plaster too long it will become rigid

The joints that adjoin a fracture stiffen the most, but less so if the fracture is completely immobilized Early, following union, these joints should be used. Any painful injury in a hand stiffens the rest of the hand, one sore finger stiffens the others Therefore if such—whether sprain, dislocation, or fracture—is primarily splinted for three weeks, which is long enough for ligament repair, there will be quicker and better recovery Proximal finger joints should be splinted flexed, not extended, as their collateral ligaments, which must be long to allow flexion, shorten in extension. If splinted flexed, they will always extend, but if splinted straight, they will not flex. In all long-disabled hands ability to raise the shoulder should be maintained, avoiding keeping the arm at the side. After setting, x ray check up should be made and again in a week, when correction if necessary is still possible.

Fractures of the hand, like other fractures, are treated by placing the distal frag

FIG. 558. Case A. W., aged 17 This is not a Madelung's congenital deformity but the retardation of growth of the radius was due to a fall injuring the epiphysis at the age of two years. Complains of awkwardness in use of hand.

ment in the line of the proximal one and exerting traction until reduced. Usually this is the functional or midposition, which is best for balanced muscle pull and for avoiding displacement in the setting of fractures. Overtraction prevents union. Anesthesia in the first 24 hours is easy by injection of 2 per cent novocaine in the hematoma or after that by the block method. In after treatment, massage, passive motion, and traumatizing physiotherapy are better supplanted by the active use of the hand by the patient, *as by occupational therapy* *If timid* he should be encouraged, and if over-strenuous cautioned in the use of his hand. Maintaining the position of function, namely, wrist in dorsiflexion, proximal finger joints flexed and other finger joints somewhat flexed, metacarpal arch curved and the thumb in moderate opposition together with persistence in active motion of all of the uninjured digits, will save months of disability Special care should be used to keep the proximal finger joints in flexion and so prevent stiffening

Strains and dislocations of any part of the hand should receive firm *compression* for the first hour by an elastic strapping to limit hemorrhage and then be immobilized *in plaster, with the* torn ligaments relaxed, and held there three weeks. This is sufficient in any dislocation for all torn ligaments and tendons to heal fairly strongly, and in four weeks they are strong Immobilization stops pain and reflex swelling thereby preventing the vicious circle that stiffens up the structures of the hand, and causes osteoporosis, vasomotor changes, and long disability

Open Fractures. Open fractures should *be operated upon with operating-room* technic promptly (within eight hours) to change them to closed ones by débridement in accordance with the principles described for fresh wounds. If the wound has been exploded, badly traumatized or dirt ground, it should be débrided and the hand should be put up in a voluminous pressure dressing. Six to ten days later, setting of the fractures and secondary closure should be carried out as described in the previous chapter Pedicle flaps from the surrounding skin and free skin grafts should be resorted to if necessary to effect the closure *Pieces of bone which* are completely loose are removed, but all those attached are saved Traction pins or wires are placed *as in closed fractures, though in some* instances it is desirable to simplify or avoid traction by attaching the fragments together with a fine No 35 stainless steel wire through drill holes made by a finger twirling pin drill. After an initial pressure dressing an air dressing is preferable. A few days of hospitalization and chemotherapy help healing In too badly traumatized wounds, as from explosions, the wound should be débrided, the fracture should be set by trac

tion, splinted, and the wound left open, using penicillin The Orr method gave good results

Infected or late open fractures are drained, immobilized, elevated, and treated with penicillin Traction pins may be placed through finger pulps unless there is active infection, in which case even setting the fracture suddenly may cause a flare up of the infection, whereas doing it gradually by traction may not When again clean, the wound may be secondarily closed, or one may choose to use curtain drainage and the Orr treatment

INJURIES OF WRIST

The wrist is a frequent site of injury by twists, strains, crushes from falling upon it or catching it in machinery Colles's fracture is the commonest lesion, closely followed by fracture of the scaphoid, dislocation of the lunate being much less frequent than either Then, in order of frequency, follow a variety of dislocations through the carpus and around the lunate and fractures of the carpal bones

A pure severe strain of the wrist is infrequent, as there is generally some fracturing in addition. Therefore, in all such wrist injuries we should not neglect roentgen examination in several views and in stereo This will frequently disclose chip fractures, fine cracks, carpal cysts, old arthritis, malalignment, semilunar dislocation, and, last but not least, fracture of the scaphoid.

In examining or searching for every clue to the exact structure damaged, comparison is made with the other wrist for deformity, swelling, or limitation of motion The lesion is outlined exactly by local swelling or edema, pain, and local tenderness. Tenderness about the complete joint circumference indicates merely arthritis or blood in the joint. Shoving up some digital ray may point to a certain carpal bone, activating the wrist in all directions, anteroposteriorly, laterally, in pronation and supination and to and fro, voluntarily and passively, with and without resistance and to the limit of range of motion, may disclose the exact ligament, bone, or other structure involved—especially if at the same time we accentuate the pain by direct digital pressure The diagnosis is made by listing and analyzing the positive findings.

Colles's Fracture

Crippling Aspects

This fracture so often cripples a hand that a few points should be mentioned The crippling is caused by incomplete setting, by immobilizing the wrist joint on a strain, by not leaving the digits free to move, and by not using the hand while the fracture is healing. Malunion results from incomplete reduction. The lower end of the upper fragment of the radius becomes a bony prominence shoving against the median nerve, and the flexor tendons are drawn tightly over it by the backward displacement of the end of the radius. This causes pain from pressure on the median nerve, and tenosynovitis and loss of function from pressure on the tendons. Due to this malunion the mechanics are upset in that muscle balance is destroyed, the flexors of the wrist, being tight, flex the wrist and fingers, and in consequence of the flexed wrist the extensors are tight and extend the proximal finger joints. The angles of approach and the leverage of the tendons are upset at the wrist joint, as they are pulling out of line. The radial deviation angulates the carpal tunnel radially, weakening the grip The head of the ulna becomes prominent dorsally from partial dislocation, and projects too long The lower ends of the radius and carpus have drawn it backward, deviated radially away from it fracturing the ulnar styloid, and have partially dislocated dorsally and longitudinally from it, thus deforming and limiting the motion of the wrist joint, and those of pronation and supination.

It is never necessary in order to maintain reduction in Colles's fracture to place the wrist joint on a flexion strain. The strain injures the joint. The digits should be entirely free, the cast being made as just described, and the patient should be encouraged to use the hand in manual work during the healing. The tendons will glide through the wrist, edema will be kept down, and stiffening of joints and adherence of tendons prevented.

Treatment

With countertraction by a sling at the elbow and a strong pull by an assistant on the thumb with one hand and on the first three fingers with the other, the fracture line is broken up and the fragments thoroughly reduced. There is no chance for overreduction, even allowing for an extra shove on the wrist in flexion to make the reduction complete, because the unbroken dorsal and radial periosteum prevents it. The articular surface of the radius should face 30° ulnarward and at least 20° palmarward by drawing out the radial deviation and the longitudinal and backward displacement. This will restore the forward curve of the radius, the ulnar deviation of the hand, and the position of the head of the ulna. The position is easily maintained by volar and dorsal nonpadded plaster slabs applied to

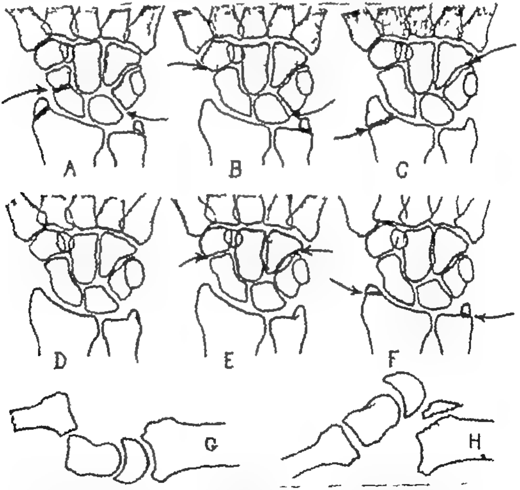


FIG. 559 Types of dislocations through the carpus with or without chip fractures of the four margins of the proximal socket of the wrist joint.

(A) Carpus dislocates dorsally transcaphoid and perilunar with or without fracture of the styloids.
(B) Radial oblique periscaphoid and lunar dislocation of the carpus.
(C) Ulnar oblique perilunar and triquetrous dislocation of the carpus.
(D and G) Dislocation dorsally of the metacarpals from the carpus.
(E) Midcarpal dislocation.
(F and H) Radiocarpal dislocation, taking with it a marginal rim.

the surface of the forearm and hand with the wrist straight and in ulnar flexion, but separated from each other by waxed paper to make them bivalve easily The cast should not extend more distalward than as described early in this chapter Colles's fracture involves the radio ulnar joint, so pronation and supination are painful Therefore, much comfort can be given the

Correction of Malunion

See Chapter 11, The Arm in Its Relation to the Hand

Dislocation of Lower Radio-ulnar Joint

The ulnar head may dislocate when the lower end of the radius is pushed away from

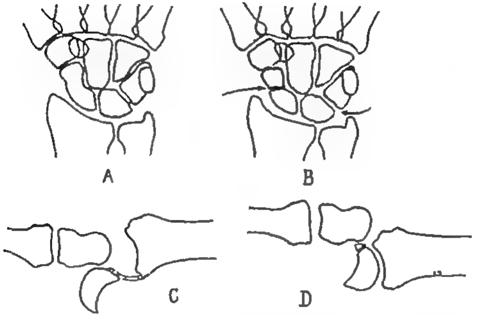


FIG. 560 Common dislocations through the carpus produced from a fall on the palm.
(A and C) Dislocation of lunate volarward from dorsiflexion and compression. Point of lunate pierces anterior capsule anterior radial lunate ligament holds furnishing blood supply but turning lunate about.
(B and D) Dislocation dorsally of the carpus transcaphoid from the lunate which remains in place.

patient by checking this motion for the first two weeks. To do this a plaster strip is laid down the outer surface of the upper arm around the elbow, up the inner surface, and there bandaged. This part of the splint can be removed in two weeks and the remainder in five weeks By stopping pronation and supination there will also be less radio-ulnar dislocation For the first few days the arm should be kept elevated on an airplane splint. It should be inspected in 24 hours and the bivalve allowed to expand a little, if necessary, to allow for swelling Later as the swelling recedes the bivalve should accordingly be tightened

it, as in fracture of the shaft or a Colles's fracture, or may do so from a severe twist, with or without fracture of the ulnar styloid. Dislocation with fracture is the more common, just as at the other end of the forearm the head of the radius dislocates with fracture of the ulna, but dislocations of the ulnar head without fracture, except of styloid processes, are not rare. After the dislocation is reduced, the head of the ulna is shoved tightly against the radius in the midposition of pronation and supination a nonpadded plaster of Paris cast is applied from the distal crease in the palm to the axilla with the elbow at a right angle

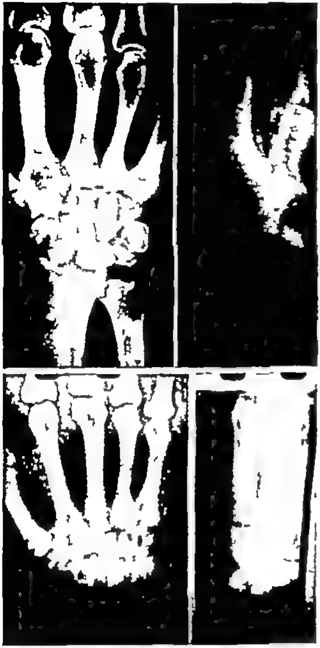


FIG. 561 Midcarpal dislocations.
(*Top*) Distal row of carpals is dislocated posteriorly
(*Bottom*) Distal row of carpals is dislocated anteriorly

and maintained for a month. The ligaments will so reunite that the dislocation will not recur Old cases of recurrent dislocation can be corrected only operatively, as described on p 297

DISLOCATIONS CARPAL, INTERCARPAL, AND METACARPAL

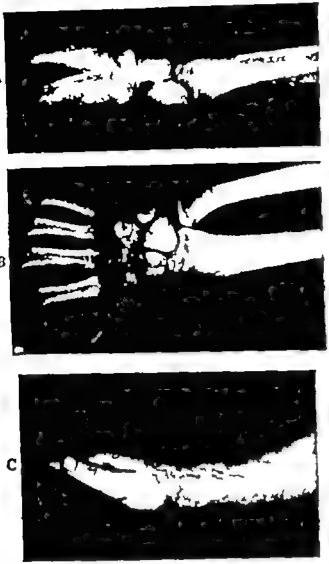
The dislocated member displaces dorsally more frequently than volarward and the dislocation may be radiocarpal, midcarpal, or much less frequently, carpometacarpal. A midcarpal dislocation frequently fractures through the scaphoid, taking the distal portion with it. As the carpus displaces, either partially or completely, a part of the radius or ulna is usually fractured off with it, either by being shoved off or avulsed. Thus, in backward force the posterior margin of the radius is shoved off, and in volarward force the anterior margin A varying-sized piece of either the radial or ulnar styloid may be fractured off in radiocarpal and midcarpal dislocations.

Reduction is made without difficulty by traction and a direct shoving pressure. In radiocarpal dislocations the carpus should be lifted and angulated around the flaring dorsal or volar border of the radius. A cast from elbow to distal crease in the palm is worn for three weeks or longer if indicated by presence of fracture

Old fixed dislocations so upset mechanics and muscle balance that they should, if causing enough disability, be reduced surgically This, though difficult, can be done using traction by Kirschner wire through metacarpal heads, severing all scar tissue that binds and prevents reduction and using gently a thin lever, such as the Davis skidder (Fig 563)

DISLOCATIONS LUNATE AND PERILUNATE

The radius curves volarward and its socket like end faces volarward, so when we fall on our palm with wrist dorsiflexed the scaphoid and lunate are covered by the overjutting radius and a Colles's fracture is produced. When, however, the force happens to be against the palm or more distal part of the carpus, as when the wrist is in strong dorsiflexion, it produces a backward dislocation of the distal row of carpal bones which often includes the distal half of the scaphoid and the cuneiform If the hand is in ulnar deviation the cuneiform is held



A

B

C

D

E

FIG. 562 Four months ago in a fall he suffered a midcarpal perilunar backward dislocation of his wrist with fracture of the scaphoid Wrist movements were limited to one-third. From muscle imbalance the fingers lacked two inches of flexing to the distal crease in the palm.

(A and B) Condition four months after the accident.

(C) Deformity Heel of palm is displaced backward. Distal to the lunate the dorsum of the hand is dorsal to the line of the forearm.

(D and E) Operative reduction After excising much scar reduction was accomplished by traction with Kirschner wire through the metacarpal heads and a Davis skidder On reduction wrist movements were again free. The proximal fragment of the scaphoid being dead was removed because such a wrist would stiffen should immobilization be prolonged.

Wrist motions are two-thirds finger motions complete. He works steadily There is slight lameness from arthritis. Bones remained in place.

down by the end of the ulna and so remains in place with the forearm bones, along with the lunate In that case, the whole scaphoid dislocates with the carpus. The capitate and carpus are thrust backward over the lunate. The latter remains with the radius Its dorsal and volar radiolunate ligaments with their blood supply remain intact.

In the lateral view there is a midcarpal dorsal bulge and instead of the rounded heel of the palm, which has displaced backward, it is flat.

Reduction is easy by straight traction and shoving If the dislocation is several months old, reduction is difficult but can be done by open operation Blood supply of the lunate is not a factor, as its dorsal and volar ligaments are preserved.

Sometimes the capitate and carpus in their backward thrust, instead of riding over the lunate, so pinch it against the radius in dorsiflexion that the lunate is shot volarward, like pinching a watermelon seed. With it may go the proximal half of the scaphoid, or, less commonly, the whole scaphoid Dislocation of the lunate alone is so common that it will be discussed separately

The scaphoid alone has dislocated dorsally, causing tenosynovitis of the thumb extensors and limitation of motion, but is

FIG. 563 Davis skidder Useful in reducing old carpal dislocations.

easily reduced under traction. The lesser multangular alone has dislocated backward. Its removal did not leave disability. The pisiform and hamate alone have rarely dislocated. In a personal old case the latter with two metacarpals five months previously dislocated backward on the cuneiform, causing much pain. Muscle balance of the fingers was upset, and the metacarpal heads projected in the palm. Replacement and lashing with palmaris longus tendon through drill holes resulted in a complete cure. The greater multangular, with its metacarpal, has dislocated accompanied by a Bennett's fracture.

Dislocation of Lunate

Description

In falling on the palm, with the wrist dorsiflexed, the weight of the body forces the radius against the head of the capitate extruding the lunate volarward. The sharp knife like point of its volar end penetrates the lunate-capitate ligament, the dorsal radial lunate ligament ruptures, and the bone escapes into the carpal tunnel, held only by its anterior radiolunate ligament. Further displacement rotates the lunate on this ligament until its concavity faces proximalward. Dorsal dislocation of the lunate by hyperflexion of the wrist is rare.

Lunate dislocation causes much disability from pain and limitation of motion. The bone presses forward against the flexor tendons, diverting them from their course, causing the hand to be held with wrist and fingers in semiflexion and the proximal finger joints fairly straight. Dorsiflexion of

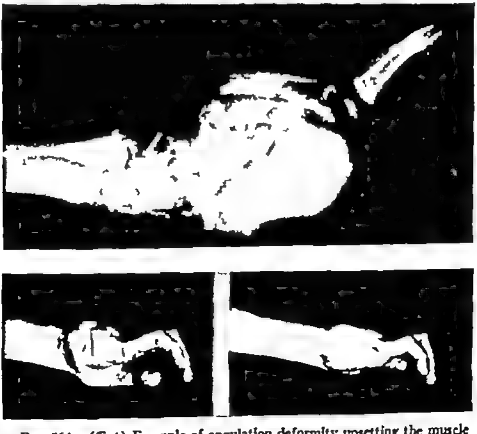


FIG. 564 (*Top*) Example of angulation deformity upsetting the muscle balance. Hand was crushed under automobile.
(*Bottom*) Showing limits of extension and flexion.

FIG. 565 Case M R.
(*Top*) Eleven days ago in automobile accident lunate dislocated forward, causing paralysis of median nerve and much pain.
(*Bottom*) Through a transverse volar incision and traction the lunate was easily reduced. Dorsiflexing the wrist made its sharp point extrude through the capsule. The rent in the capsule was sutured Causalgia followed but left in eight months.

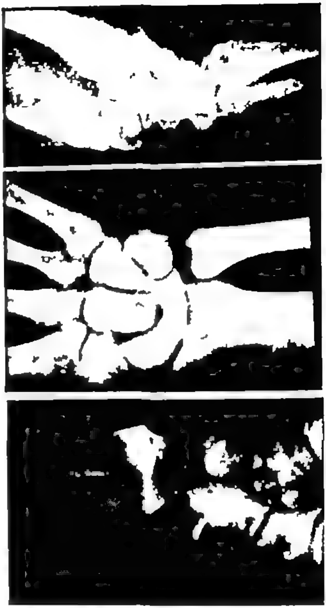


FIG. 566 Two examples of dislocations of lunate.
In the case shown in the center and bottom illustrations, the median nerve was paralyzed The paralysis cleared in a month after open reduction and suture of the rent in the anterior ligament.

the wrist is painful and the tendons cannot close the fist. The wrist is thick and tender volarward between the two flexion creases which mark the lunate, and there is a dorsal hollow The lunate also presses on the median nerve with intense pain, causing paresthesia, anesthesia, paralysis of the muscles of opposition, and atrophy in the median area The hand may be spastic from pain In complete displacement such disability is permanent, but if the dorsal radiolunate ligament has not been ruptured so the displacement is only partial, the permanent disability may be slight

If unreduced, arthritis develops in the wrist joint, affecting mostly the bones in the vicinity of the lunate—it is probably more from mechanical disarrangement than from lack of blood supply of the dislocated bone, which is still supplied through its anterior ligament. Strangely enough, Kienbock's disease has not been known to develop from dislocation of the lunate (Böhler), the latter being more the result of an explosive crush of the bone than from cutting off the blood supply

Treatment

Considering that the lunate retains its blood supply by its intact volar ligament

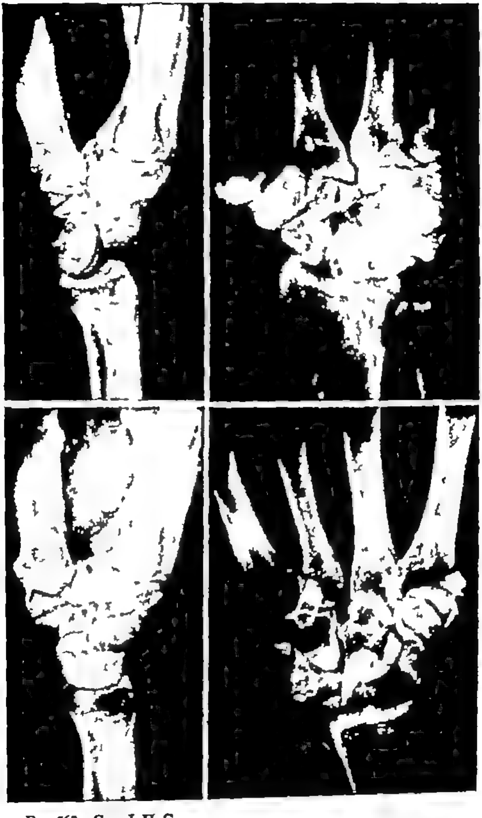


FIG. 567 Case J H. C.

(*Top*) A fall down stairs on the hand fractured the navicular and dislocated the lunate.

(*Bottom*) After unsuccessful attempts at closed reduction the lunate was exposed through a small transverse volar incision. With traction on the fingers slight pressure on the distal horn of the lunate reduced it. Through a short transverse dorsal incision the small fragment of scaphoid was removed, thus avoiding the months of immobilization of a badly injured wrist and resulting in prompt relief and return to work.

to the radius, it will, when reduced, retain its vitality Closed reduction is usually possible The obstacle is the back of the posterior horn against the head of the capitate. *Strong or prolonged traction*, with fingers straight so the taut flexor tendons will press on the lunate, will free the horn from the capitate and *allow reduction* Böhler advises 10 minutes of steady traction. Closed reduction may be successful up to two weeks, but not afterward

Failing by the closed method, reduction is easy by open operation under block anesthesia and traction by Kirschner wire through the metacarpal heads By merely tilting, with a pointed instrument, the posterior horn around the capitate head, the lunate pops into place It again extrudes on dorsiflexion, but is held in place on flexion. After closing the ligamentous rent with fine chromic catgut, the wrist is put up in a half plaster of Paris cast in slight flexion. In a week it is changed to the straight position and in three weeks the cast is removed

If accompanied by fracture of the scaphoid, in some cases by removing the proximal scaphoid fragment if it is small, convalescence will be shortened and long immobilization *of a badly traumatized wrist will be* spared. If the fragment is larger, the limb should be kept many months in a cast for the scaphoid fracture to heal

Old Dislocations. Old unreduced lunates give disability, whether replaced or removed, due to arthritis If removed before arthritis develops (which is good treatment) the disability will be but slight, consisting of some weakness and limitation of motion. The gap between the carpal bones does not close. If removed after arthritis has developed the arthritis will still be permanent, but the wrist will be improved In neurospastic cases, or if the lunate shows a relative excess of calcium indicating necrosis, or is so far displaced as to lose its blood supply, *or even if six months have* elapsed, immediate excision is advisable before arthritis develops. If, however, by x ray appearance the bone is viable and there is no arthritis, open reduction is advisable and possible under skeletal traction *with the help of a Davis skidder The dis*location is reduced, great care being taken not to traumatize the carpal bones by leverage or to destroy the remaining blood supply of the lunate. Such trauma, unless specially guarded against, frequently occurs and will, itself, cause arthritis


FIG. 568 Fracture of hamatum.

Fracture of Carpal Bones

Of the carpal bones, the three in the proximal row are more frequently injured They constitute the heel of the palm, and in falling palm down on the dorsiflexed wrist are pressed between the ground and the forearm bones. The scaphoid and lu*nate*, being overhung by the radius, are fractured more often, the scaphoid by far the most as the radiostyloid acts as a wedgelike fulcrum against its center

The relative frequency of fractures about the wrist is shown by the statistics of

Schnek of Böhler's Clinic Of 669 fractures and epiphyseal separations of the lower end of the radius there were 437 cases of carpal injuries, consisting of the following

Fracture of scaphoid	154
Fracture of lunate	23
Avulsion of posterior horn of lunate.	59
Fracture of triquetrum	[illegible]
Fracture of greater multangular	13
Fracture of pisiform	13
Fracture of hamate	8
Fracture of capitate.	[illegible]

Snodgrass reports from the Episcopal Hospital in Philadelphia the order of frequency of carpal bones fractured as follows

Scaphoid	144
Lunate.	11
Triquetrum.	7
Pisiform	1
Greater multangular	3
Lesser multangular	1
Capitate.	2
Hamate	1

Fracture of Scaphoid

Fracture of the scaphoid is common, of the lunate fairly so but of the other carpal bones rare or merely chip fractures. With the exception of the scaphoid all have good blood supply and heal readily with a month

FIG. 569 Dislocation of pisiform bone (left)

of immobilization, though a crushed lunate needs traction for twice this time.

Of fractures about the wrist, the scaphoid is next in frequency to Colles's and is especially frequent in young adults. In our Army its incidence was greater than that of Colles's fracture. The scaphoid is covered in dorsiflexion in its proximal half by the radius, its distal half projecting. In a fall on the palm with the wrist forced in dorsiflexion and radially deviated, the tuberosity which is the distal point of the scaphoid receives the impact, and the pointed radiostyloid and dorsal margin press midscaphoid in such a way that by leverage the scaphoid breaks across The scaphoid is extra vulnerable, as anatomically it spans the length of both rows of carpal bones and is fractured across its neck against the styloid as the second carpal row bends backward on the first, which is imprisoned under the radius. Schnek pointed out that a large radiostyloid predisposes to this fracture. In normal radial deviation of the wrist the scaphoid

must angulate forward to avoid the radio styloid, as may readily be felt by placing a finger on the tubercle Fracture of the tuberosity is by avulsion

Symptoms. Swelling and edema which are only moderate are greatest locally, and there is local pain on wrist motions and in grasping Tenderness is present at the tubercle and in the snuffbox, and pain is elicited by shoving upward on the first two digital rays. Wrist motions are moderately limited. So frequently is this common fracture overlooked that in cases of seeming sprain of the wrist we should not neglect careful search by x ray Many fractures are overlooked as they may not show in the usual lateral and anteroposterior views because the long axis of the scaphoid is in an oblique position In ulnar flexion it deviates 22° forward, in radial flexion, 60° Dorsiflexion of the wrist brings the scaphoid more in a line with the forearm, but then it is partly overshadowed by the mult

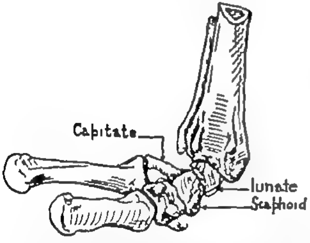


FIG. 570 A fall on the palm when wrist is slightly dorsiflexed may produce Colles's fracture. In complete dorsiflexion the radius covers the lunate and half of the scaphoid. A fall on the palm then may produce any of the following

(1) It may drive the carpus dorsalward as a perilunar dislocation. If the forearm is oblique in the lateral plane either of the two oblique perilunar dislocations may occur

(2) The dorsal edge of the radius may crack the scaphoid in two

(3) The lunate may be expressed forward from the carpus by dorsiflexion and the compression of the radius.

FIG. 571 (*Left*) Fracture of scaphoid Both fragments nourished Unites if immobilized.
(*Right*) Same united taken a year later

angular bones In order to aim the rays at a right angle to the bone the wrist should be ulnar flexed The patient should be sitting with both hands raised over and back of the head Each index knuckle should rest on the plate Then with the thumbs together, the palms at a 45 degree angle to the plate, and the index metacarpals at a 30 degree angle with the plate, the vertical ray will give symmetrical pictures taken at a right angle to the long axis of each scaphoid For position it is the hand that is moved, not the direction of the rays. To find an oblique fracture, slightly different angles may be needed Unless searched for *in several directions, the tiny line indicating* the crack through the scaphoid will be overlooked. Even so if symptoms point to the *fracture, new films should be taken after* an interval of three weeks, as by then the fracture line will have spread and will show clearly

Bipartite Scaphoid. Bipartite scaphoid is rare but when found may be confused *with fracture either of the two distal* corners may be separate or cartilaginous, or there may be a separation at the waist, *there having been two centers of ossification* instead of the usual one for each carpal bone Points to consider in differentiating *are the presence of the same in the other* carpus or of other abnormalities, the absence of history or signs of injury in this *incidental* finding and the rounded, clear

cut edges, with equal bone density of each part, in contrast in fracture to the irregular margins and patchiness or increased density of lime in the proximal fragment. Subsequent x ray films show absence of the bone changes seen in fracture. Gollasch reported this rare condition in ten relatives

Nonunion Frequent. There are two reasons why fracture across the scaphoid if untreated does not unite excess of

FIG. 572 Bilateral fracture of scaphoid. A long radiostyloid predisposes to this fracture.

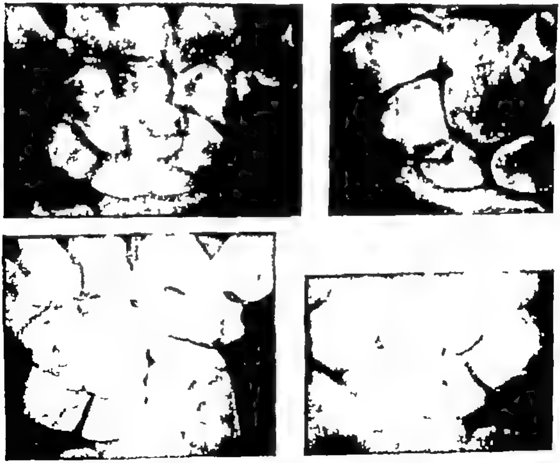


FIG. 573 Fractures of scaphoid.
(*Top*) Show beginning degeneration, and in the right hand illustration some sequestration.
(*Bottom*) Old ununited fractures with arthritis in adjoining parts.

movement and deficiency of blood supply

Half of the lateral movement of the wrist is by the midcarpal joint, the cleavage plane of which normally curves to emerge through the first interdigital cleft (Fig 574) With a break across the scaphoid, this shearing movement with the amplitude of a centimeter takes place through the fracture line. Also the scaphoid angulates forward with each radial deviation to avoid the radiostyloid, and also with each motion of opposition of the thumb Every advance of tissue growth toward union is sheared away until finally the two surfaces become eburnated.

The heads of the femur, radius, and scaphoid receive most of their blood supply from the main bone, so when fractured off have insufficient circulation either to unite or to have their calcium absorbed, thus, instead of sharing in the rarefaction of the surrounding bones the fragment shines out by x ray with its original density

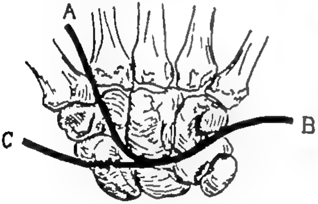


FIG. 574 Nonunion occurs after fracture of scaphoid because both blood supply and immobilization are insufficient. Line of motion in lateral movement of the wrist is normally along A–B through the first cleft. When the scaphoid is fractured it is along C–B shearing the fracture line at every move.

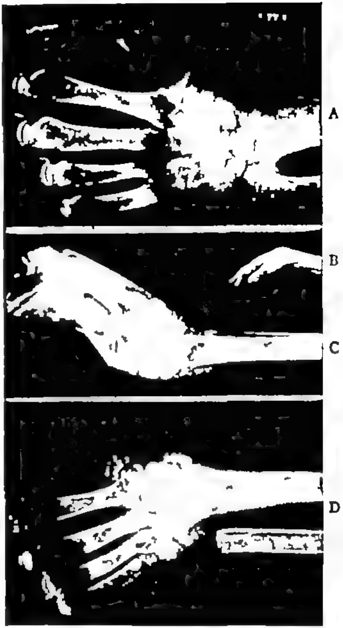


FIG. 575 End result of nonunion of a fractured scaphoid. Patient told of a sprained wrist 20 years ago" and "rheumatism" in the wrist since. In the last year he could not use the hand.

(A) The sequestrum of the upper end of the scaphoid is conspicuous and also the resulting arthritis including the radio-ulnar joint.

(B *insert*) The deformity

(C and D) The wrist was arthrodesed and the head of the ulna excised for free rotary movement.

The scaphoid is so mobile that most of its surface is encased in cartilage, there being five articular surfaces, each of which moves on a different bone. Entrances for blood supply are the foramina seen in the small nonarticular areas some at the two margins of the lower pole and the remainder along the narrow dorsoradial ridge, only tiny ones, if any, reaching to the upper pole The number and location of these foramina vary, the larger ones extend along the ridge from the tubercle to the superior articular facet, some of which may be

found a way farther under its overhanging dorsal edge. They are distributed so that in a fracture through the waist each fragment will in the majority of bones have circulation but in the minority, the proximal fragment will not. The more proximal the fracture line, the more avascular will be the upper fragment.

All fractures through the tubercle, which is vascular and extra articular, unite whether splinted or not. Most fractures through the waist, if immobilized eight to ten weeks, will unite, as both fragments have circulation (Böhler claims 100 per cent unions) A proportion of fractures more proximal either do not unite or require, even with perfect immobilization, as long as a year for union. The time required is for creeping substitution, as in the case of the femoral head The proximal portion dies, and is gradually replaced through ingrowing blood vessels.

If there is movement or displacement the fracture, even through the waist, can never unite In one or two months the gap becomes wide and of cystic appearance. The distal fragment rarefies and may become cystic. The proximal fragment, if avascular, will in the course of several months show as a sequestrum In a sedentary individual there may not be much complaint from nonunion But if he should do manual work, the hand will swell and become lame The inevitable result of nonunion, and especially if one fragment has sequestrated is arthritis which gradually, in the latter case, involves the whole wrist It first shows in the radiostyloid and then in the adjoining carpal bones—the lunate and capitate—there being distortion hypertrophic bone growth and erosion of cartilage.

Treatment. Immobilization in Non padded Cast Treatment was by excision until recently It has been conclusively shown that union will occur if immobilization is complete and prolonged Immobilization is the key to success, not the position in which the limb is placed With the carpus exposed it is seen that abduction of wrist or thumb or using any other position does not bring the fragments together Nothing less than shoving up the first and fifth rays will tighten the fracture line. The fact that men using different positions all succeeded eliminates position as a factor Even so, position may be used to stimulate union. A hand in the position of function will be used, and use without displacement makes bones unite

A padded cast or leather wristlet does not sufficiently immobilize. A nonpadded cast fulfills the requirements of immobility if snugly molded and properly made. It should include three-quarters of the length of the forearm and the hand, which should be placed in the position of function of mild dorsal and ulnar flexion and with the thumb in moderate opposition. The fit about the head of the metacarpal of the thumb should be snug, leaving the distal two segments free to move, and the cast should end at the knuckles and distal crease in the palm for free exercise of the fingers. The hand should be used freely at work to keep it in good condition, preventing stiffness during the long period of immobilization of the wrist. Periodically, when the hand becomes loose in the cast, a new cast should be applied. A coat of Duco will protect the cast The addition of one or two crossed Kirschner wires through the scaphoid ensures immobility Later, the wires are retrieved from beneath the skin Similarly, a screw has been used

The average time for union is twelve weeks, but as in some the proximal fragment will be avascular, the rule should be to continue the immobilization until union is seen by x ray the criterion being obliteration of the fracture line, crossing of it by lines of force, and equal density in the two ends of the bone. Here again the picture should be taken in several views, to be certain.

The fragments must, of course, be in position or molded so under traction When properly immobilized and in position practically all should unite. The cases that come with nonunion are the untreated ones

FIG. 5/6 (*Left*) Nonunion of fracture of scaphoid after three months without treatment Upper fragment has lessened blood supply
(*Center*) X ray appearance four months after pegging later Union is firm in spite of the avascular upper end.
(*Right*) X ray appearance nine months later Ends of scaphoid almost equal in density

that were thought to have been merely sprains All such with signs suggesting fracture of the scaphoid should be x rayed in several directions to pick up any oblique crack and then placed in a nonpadded cast. 'Skin tight" is a pernicious term as it leads to gangrene. In applying a nonpadded cast, the plaster is merely laid on In three weeks a second x ray picture should reveal a fracture line if present. If not, the sprain will have been well treated If the fracture is several months old immobilization will still succeed, but it takes longer Even a dead head has in this way been made to unite in one or two years McKim reports a case of nonunion for two years which united well after 9¼ months of immobilization

Under certain conditions when the chances for union by prolonged immobilization are poor or impossible, or when long treatment is not advisable, an operative procedure is indicated Thus, if the proximal fragment has sequestrated it is best excised. If in a complicated carpal injury involving the lunate and others the proximal fragment of the scaphoid is small and loose, a long siege of stiffness will be spared by excision In cases of wide separation and with some relative increased density, one must excise or bone graft

If both fragments are rarefied or cystic there is sufficient circulation, and long immobilization will suffice Here, drilling to increase blood supply is superfluous If, though, the ends are eburnated or one fragment is denser, drilling often succeeds in restoring circulation and union, but more positive action is to insert a bone peg

Bone grafting is advisable in delayed cases, in insuring quicker union by more complete immobilization and bony continuity It is a shortcut for slow healing fractures and will bring blood supply to a partially dead head It is indicated when the fragments are eburnated or even in a fresh case when they are separated If, in three months or over, there is nonunion, and operative conditions are good pegging is justifiable If in operating the bones are traumatized or the blood supply of the scaphoid is torn arthritis may develop

Gordon Murray found that, in 100 cases

of bone grafted scaphoids, 40 per cent showed aseptic necrosis of upper end, but that union was obtained in all except one and even he was able to return to work. In a later report of a larger series 96 per cent fused From bone grafting the proximal fragment became vascularized and lived. Fractures through the waist, which constitute three-fourths of the cases, if in position and properly immobilized should all unite. Similarly most of those through the upper pole unite in time, though here the blood supply is doubtful Of fractures of the tubercle, which constitute 10 per cent, all unite. It is the undiagnosed, and, therefore, untreated fracture that results in non union

Excision In all cases of sequestration of the proximal fragment, excision should be done early to prevent inevitable arthritis. If done later it helps the hand, but the arthritis does not clear up

It is usually the proximal fragment which is excised but at the same time the sharp edges of the distal fragment should be rounded over to articulate with the radius After excision of a part or all of the scaphoid there is usually some permanent disability of weakness of grip and limitation of motion, and the hand deviates radially Frequently, however, especially in people who do not do manual work, there will be

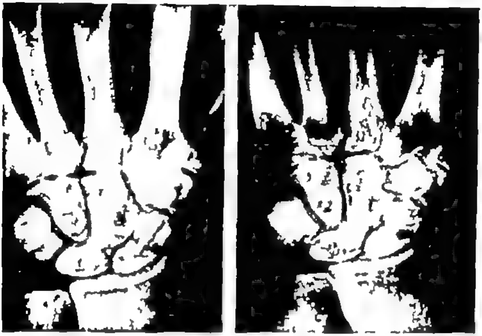


Fig. 577 (*Left*) After four months without splinting the scaphoid was pegged with a piece from the ulna.
(*Right*) Bony union followed. X ray view taken six months later

little or no complaint. Arthrodesis between the os magnum and the two parts of the fractured scaphoid has been suggested by Sutro Three out of his four cases united. This will limit lateral motion of the wrist one-half Arthrodesis with the lunate as is normal in carnivores, has also been suggested to bring good blood supply to the scaphoid fragments.

In an old case of fractured scaphoid the arthritis, if either progressive or crippling, calls for arthrodesis of the wrist. In such cases a bone graft is unnecessary, as broad approximation of the wrist bones can be obtained, otherwise a flat graft of ilium is inserted

Bone Grafting. Each pole of the scaphoid is exposed through a separate small incision paralleling the skin creases. The tuberosity is easily felt and uncovered To expose the upper pole in the snuffbox the skin is first undermined superficially, then

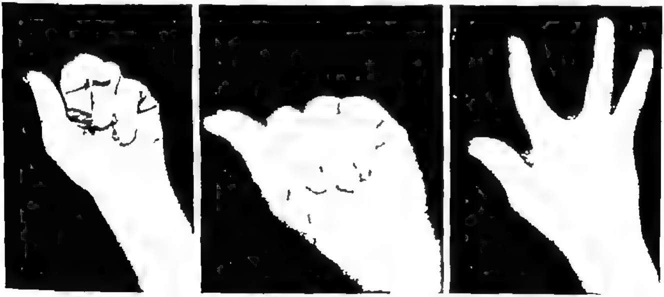
through a longitudinal incision in the super ficial fascia the twigs of the radial nerve are drawn aside The wrist must be strongly flexed to present the proximal pole The extensor tendons of fingers and the tendon of the extensor carpi radialis brevis are retracted ulnarward Care is taken to avoid damaging the blood supply of the scaphoid, which is along the dorsal ridge The frac

Fig. 578 Instrument for pegging a fractured scaphoid. Through two short transverse incisions the two ends of the scaphoid are exposed and grasped by a volsella, jamming the fragments together at the fracture line. To the volsella is soldered a guide with two holes to guide the drill in aiming true through the two fragments. A peg of tibia is then tapped into the drillhole

tured ends are freshened, and while held tightly together and impacted with a two-prong volsella, are drilled By sighting on the forceps, first a small pilot drillhole is made and followed by one ¼ inch in diameter As a guide for the drill a metal piece may be soldered to one jaw of the volsella (Fig 578) with two holes exactly in alignment Into the hole in the scaphoid a graft from the ulna is tapped and the volsella is released There should be no trauma to the adjoining joint surfaces nor to the blood supply along the dorsal ridge A nonpadded cast is applied

Barnard exposed the scaphoid by excising the radial styloid which he used for the graft.

Carrying to the scaphoid our principle of pinning bones in the hand, the scaphoid, exposed at each end and its fragments squeezed together with a vulsellum, may be accurately fastened by two cross pins Just as in hips a miniature flanged nail may be used



A B C

Fig. 579 Case C T H. Showing the crossing of fingers in flexion due to an amputation of the long finger proximal to its metacarpal head. The adjoining metacarpals not having the support of the intervening head, rotate toward each other palmward, exaggerating the transverse metacarpal arch and tilting the axis of the joints toward each other Showing also limitation of flexion of the fingers due to the fixation of the flexor tendons of the amputated finger to the stump. As the flexor tendons arise from practically a common muscle the fixation of one tendon limits the excursion of the rest of the tendons.

Operation. By severing the flexor tendons of the long finger in the palm, and by removing the whole of the third metacarpal, normal function resulted, as shown in (B) and (C)

FRACTURES OF METACARPALS AND PHALANGES

Fractures of Metacarpals

Fractures of the metacarpals and phalanges are the most common of all fractures. Of these the proximal phalanx comes first and the neck of the fifth metacarpal second. Distal to the radius in order of frequency are fractures of the phalanges, metacarpals, and scaphoid. Of the metacarpals the fourth and fifth, which from their position are subject to trauma, are fractured most often. The fracture may be near the base, in shaft or through the neck, but always the distal fragment angulates volarward. Neck fractures are usually from blows, the fifth metacarpal being in the most vulnerable position. Shaft and base fractures are often from crushes by heavy objects or machinery and so are frequently multiple, comminuted, and open. Spiral shaft fractures are from rolling twists with the fingers flexed at their proximal joints as levers. Malunion and nonunion are discussed in Chapter 6 and fractures from gunshot wounds in Chapter 12.

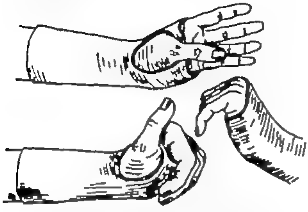


Fig. 580. Correct way to apply a cast to hand and forearm. All fingers are free to move because the cast does not extend further than the distal flexion crease in the palm and the thumb is free because the cast ends at the thenar crease. Wrist is in moderate dorsiflexion. Proximal finger joints can be flexed and the thumb opposed. (Courtesy of The Bulletin, U. S. A. Med. Dept.)

Metacarpal fractures are disabling in several ways. Malunion upsets muscle balance, producing a clawed finger, and the head of the metacarpal projecting in the palm against the nerves limits grasping because of pain. Malunion of rotation makes the fingers deviate or cross on flexion. Extensor and sometimes flexor tendons adhere in the callus. The interosseus muscles may be damaged and often their tendons adhere to the firm parts beneath so they cannot flex the proximal finger joint or extend the distal two. In open fractures, especially gunshot wounds, these important soft parts closely surrounding the bone may share in the injury and become embedded in the scar.

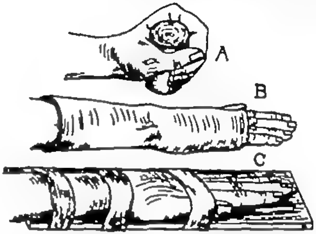


Fig. 581. Three incorrect ways of splinting a hand, all of which contribute to crippling.

(A) Bandaging all fingers over a roller bandage stiffens the hand as a whole and the joints of all fingers. Only the injured digit should be splinted and the others free to move and be kept moving.

(B) A plaster cast should not be applied with the wrist and fingers straight and should never include uninjured fingers beyond the distal crease in the palm. Result: Proximal finger joints will be stiff and straight, and the whole hand and forearm unexercised. Wrist, arches, thumb and fingers should be in position of function.

(C) Strapping a hand to a board stiffens the whole member and in a position of nonfunction, namely with wrist straight instead of dorsiflexed, palm flat with loss of metacarpal arch, thumb at side of hand instead of in opposition and finger joints straight. (Courtesy of The Bulletin, U. S. A. Med. Dept.)

A most common and troublesome complication is that of stiffening of the proximal finger joints in the straight position. This happens not only from proximity of the fracture, but because when splinted in the straight position the collateral ligaments become so short and thick that they will no longer allow flexion (see Chapters 7 and 12). If splinted in the flexed position, these ligaments are kept long and leave the joint free to move.

Signs of the fracture are the hump on the

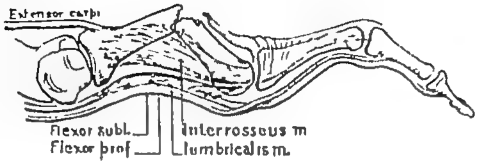


FIG. 582 Deformity with fracture of metacarpals.
Three extensor carpi dorsiflex the proximal fragments and the intrinsic muscles and long flexors flex the distal fragment. The long extensor is tensed over the fracture and dorsiflexes the proximal finger joints. There is a bump in the dorsum of the hand and the head of the metacarpal projects into the palm.

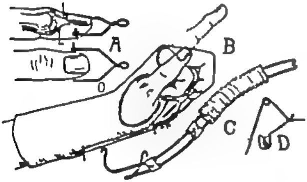


FIG. 583 Correct method to apply pulp traction for fracture of phalanx or metacarpal.

(A) Pin transfixes at correct site, avoiding matrix (upper arrow), nail, phalanx and tendon sheath (lower arrow).

(B) Plaster cast embraces hand and forearm, stops at distal crease in palm leaving the uninjured fingers free to exercise throughout their range of motion and at thenar crease giving thumb free motion of opposition. Finger whose phalanx or metacarpal is injured rests on padded wire extension (as in C) which is incorporated into plaster. A cord from wire to cast at forearm maintains the flexion.

(C) Extension made of soft iron wire with two strips of tin and padding. A strip of duralumin may be used instead.

(D) Method of using a steel safety pin for pulp traction. Point after transfixing is cut off. (Courtesy of The Bulletin U S A. Med. Dept.)

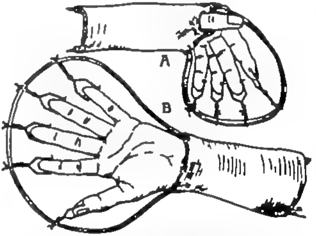


FIG. 584 The banjo splint wrecks many hands. Pulls fingers in straight or wrong position which throws fractures out of line and stiffens all joints of digits.

Fingers with traction should rest semiflexed on an extension support, as in Figs. 583 and 586.

(A) Fingers in semiflexion should converge. (See Fig 586.) Fingers are pulled straight and diverging. Thumb should not be enclosed in cast and wrist should be in dorsiflexion.

(B) Digits are pulled in wrong or straight position and are not really splinted as hand flaps back and forth. Will result in much stiffening and malunion. Courtesy of The Bulletin, U S. A. Med. Dept.)

FIG 585 Fractures near the middle finger joint.

(A) From direct injury in a child.

(B) Chip fracture from compression.

(C) Chip fracture from angulation. Needs traction and molding.

(D) Chip fracture with dislocation.

(E) Same, with dislocation held reduced by stainless-steel pin placed just beneath skin for later removal.

(F) United but with some limitation of movement.

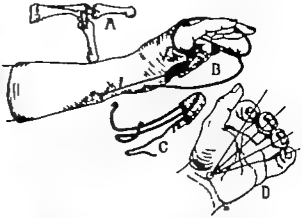


FIG. 586 (B) Correct method of applying skeletal traction for fracture of metacarpal. Wrist is dorsiflexed 20 and proximal finger joint flexed 45 Thin Kirschner wire transfixes neck of proximal phalanx *and is bent, as shown for traction to stiff* wire extension loop from plaster cast Finger is steadied by adhesive plaster on a wire extension (as in C) to maintain correct rotation. Skeletal traction on the fingers is rarely needed.

(A) Shows collateral ligaments of proximal finger joint tight in flexion but relaxed in extension. If this joint is splinted in extension these ligaments so shorten that the joint cannot be flexed. If splinted in flexion and with skeletal traction the joint *remains limber*

(D) Showing guides to correct rotation in setting fractures. In partial flexion planes of fingernails form an arch. Planes of motion of the fingers converge to the tubercle of the scaphoid. (Courtesy of The Bulletin U S A. Med. Dept.)

dorsum of the hand and the prominence of the metacarpal head in the palm On sighting along the knuckles, compared with the other hand malalignment shows along the dorsum as a depression and along their ends as a recession or shortening from bowing or overlapping Shoving up that ray elicits pain, and there is tenderness over the fracture.

The deformity of dorsal buckling, with the distal fragment angulating volarward, is produced somewhat by the three extensor carpi muscles drawing the proximal fragments of the second, third, and fifth metacarpals *into extension, and more by* the intrinsic hand muscles and the long flexor tendons of the fingers, all of which are in a plane volarward, flexing the distal fragments. Buckling of the metacarpals upsets the muscle balance from there distally, dorsiflexing the proximal finger joint and flexing the distal two

Treatment. The wrist is dorsiflexed to relax the extensor carpi muscles and to have muscle balance in the position of function. The fingers are flexed to relax the long flexor muscles and interossei, and by traction and pressure molding on the dorsum the bone comes into alignment. The setting is done manually and the position is maintained by a splint and traction

A

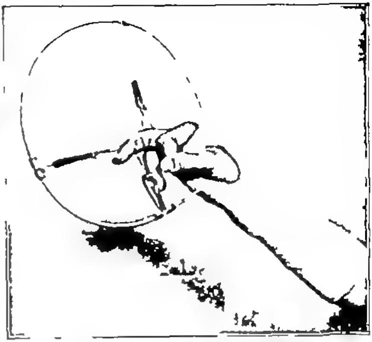


B

FIG. 587 Showing fracture dislocation of proximal interphalangeal joint
(A) Before reduction
(B) Apparatus used in treatment
(C) Reduction with traction applied.
(D) Final result (Courtesy of R. C Robertson J J Cawley Jr., and A. M Faris Treatment of fracture dislocation of the interphalangeal joints of the hand. Jour Bone and Joint Surg 28 70 Jan 1946)

C



D

For a metacarpal the nonpadded plaster cast should always include the forearm and be molded against the metacarpals on the dorsum of the hand to the knuckles. Incorporated in the cast, over the palm and wrist, is a malleable extension curved to fit the volar surface of the finger and long enough for attachment of the traction. A cord from the end of this to the wrist maintains the curve. These extensions are for one or more fingers and may be of aluminum strip, but preferably consist of the long, padded, annealed iron wire loop popularized by Böhler The curve is so made that the proximal finger joint is flexed from 20 to 45°, the middle to 90°, and the distal to about 45° Too much flexion of the proximal joint cocks up the distal fragment, too little allows the proximal joint to stiffen in the straight position. The greater the damage, as in gunshot wounds the more necessary it is to keep this joint flexed as the edema and immobilization result in tightening the collateral ligaments Flexion of the joint keeps these ligaments long Traction also, lengthens them especially skeletal, applied to the proximal phalanx.

The reason for the curve of the metal extension is to maintain the fingers in the position of function Midway in their range of motion the fractures have less tendency to displace After the first manual setting, the traction is applied pulling the finger around the pulley The metal extension constitutes the pulley

If there is no displacement, traction is made by spiral adhesive plaster on the finger but if the fragments are displaced, it is made by stainless steel wire or pin through the tough finger pulp In severe injuries, skeletal traction from the proximal phalanx is preferable so as to elongate the collateral ligaments of the proximal finger joint.

For pulp or skeletal traction a fine Kirschner wire, cut off obliquely, is either inserted through the pulp or drilled through the head of the proximal phalanx avoiding the joint and dorsal aponeurosis Each end of the wire is bent down the finger to end ½ inch

FIG. 588 Effect of overzealous pulp traction. Obviously palm wound should have been closed before dense fibrosis had frozen the underlying tissues. (Courtesy of D W Macomber Lt. Col., M.C., O'Reilly General Hospital.)

beyond the finger tip in a ring or hook, to which is attached the traction cord. Special traction bows or steel safety pins may be used.

Traction has so often been wrongly applied, both in placing the wire and pulling at the wrong angle, resulting in much damage, that directions for its accomplishment should be studied. In the pulp the pin should penetrate from side to side opposite the center of the nail just anterior to the phalanx. It should not penetrate the matrix joint or flexor tendon sheath or be placed just under the flexor tendon, and should not be placed anteroposteriorly The pulp soon acquires a tough chitin like coating Nail traction pulls out the nail A towel clip has been used for traction on a metacarpal head. If placed on the head of the proximal phalanx, its handles may be embedded in the plaster cast in the palm The point of a large fishhook or curved S.S wire has been used for traction, hooking it into a drill hole on the dorsum of the proximal or middle phalanx (Quigley)

The dorsal hump is avoided by direct pressure and traction Correct rotation is determined by the planes of the finger nails and by observing that the plane of motion of each finger converges to the tubercle of the scaphoid. Immobilization is maintained for three to four weeks according to the severity and age during which time all the uninvolved digits should be free and moved

FIG. 589 (*Top*) Fracture of neck of metacarpal with usual deformity Distal fragment is controlled through phalanx after flexing the joint to a right angle.
(*Bottom*) Pad under middle knuckle and cast as shown maintain position.

frequently by the patient through their full range passively and as much as he can move voluntarily to keep the hand in condition and prevent stiffness Neither should the finger be flexed over a roll of bandage which increases the deformity and prevents exercise of the other fingers, nor should the finger be pulled straight in extension by a banjo splint or held so by a straight splint as either displaces the fracture and stiffens the fingers. A flat splint straightens the arch

The ball splint was like a baseball. A bandage or a strip of adhesive plaster about the hand and through the hole in the ball kept it in place A rounded dome on the end of a metal forearm is similarly useful However, both of these devices immobilize all of the digits instead of only the injured one and do not furnish the necessary traction to straighten the fractured bones.

Fractures through the metacarpal neck, with angulation volarward and sometimes laterally are difficult to set by the method described but easy by the following

The distal fragment is poorly controlled

because it is short and the proximal joint is so mobile If, though, this joint is flexed to a right angle, it is firm and the fracture can be controlled through the phalanx A thin piece of felt is placed over the middle knuckle, which is also bent to a right angle place through joint and skin until it is firm

A method suggested by Berkman and Miles and that has been proven to be good is to maintain position of a fractured meta carpal by one or two narrow Kirschner wires, drilled at a right angle through two

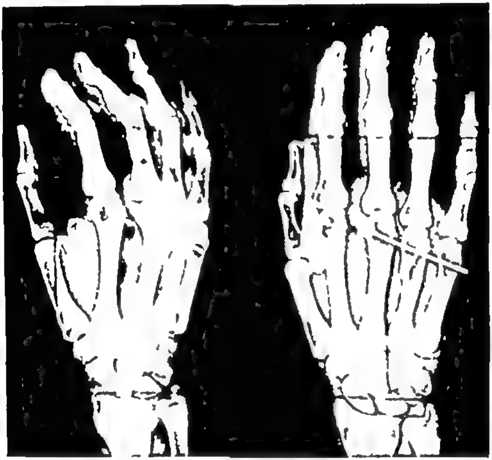


FIG. 590 Fresh fracture pinned. Kirschner wire is cut beneath the skin to avoid infection. Cast is not necessary

By firm pressure on this the metacarpal is straightened, and checked by its head's be ing in correct knuckle alignment The fore-arm and hand are encased in plaster and the plaster strip is placed the full length along the dorsum of the finger, merging with the cast on the dorsum and in the palm to main tain the position. If for any reason the fracture does not remain in position, it may be held by a stainless steel pin pinning it transversely to the other metacarpals

If a fracture or piece of bone such as fragment of phalanx or metacarpal head or a dislocation, cannot be held in place, there should be no hesitation in opening and fastening it firmly by a fine stainless steel wire or by a stainless steel pin left in or three metacarpals The need of a cast is eliminated and the free exercise prevents joint stiffness The wires should be cut off beneath the skin, thus eliminating a dressing and the danger of infection due to movement. They are removed later under local anesthesia

In open fractures good skin should be placed on the dorsum of the hand at once if possible, by swinging a neighboring skin flap and split grafting or resorting to a pedicle graft. Treatment of mal and non union is given in Chapter 6

Fractures of Phalanges

Finger fractures are so frequent and r sult in so much disability that they cau

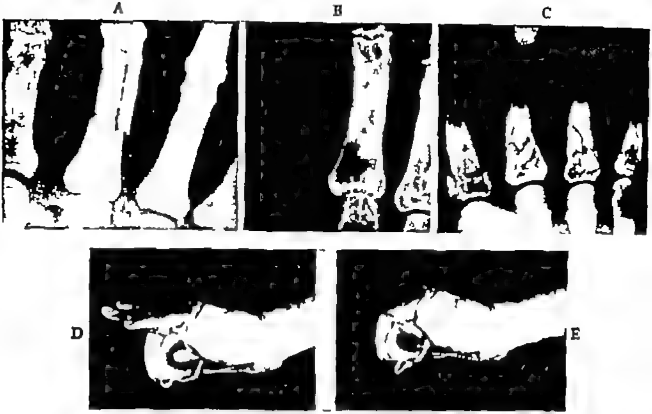


FIG. 591 Fractures of proximal phalanx from direct violence and without displacement. Skin traction is sufficient to hold these fractures as shown in (D) and (E)

(A and B) Longitudinal fracture fresh and a year later

(C) These fractures solidified promptly as in (B) Without displacement tendons are not so likely to become adherent.

(D and E) Fixation for fractures of proximal phalanx of fingers. Plaster includes forearm, stops at distal crease in palm to allow flexion of other fingers as shown in (E) Padded wire loop extension as used by Böhler holds the injured finger using skin or pulp traction.

about as much compensation expense as do fractures of the long bones. The proximal phalanx is fractured almost twice as frequently as the middle or distal, and the distal twice that of the middle. From direct or indirect force the shaft or either end of the proximal or middle phalanx may be fractured and often comminuted. In joints, an edge is often pushed off or torn off from overangulation in any direction, resulting in long lasting painful stiffness If replaced and immobilized for three weeks in a splint, most of this disability can usually be spared. One painful finger may reflexly stiffen a whole hand, but does not do so if it is promptly immobilized, leaving the others free to move until healed

Joint stiffening in fingers is a necessary evil, especially if the fracture is in or near the joint, greatest in the joint involved, but also involving the others This tendency to stiffen, and the frequency of the flexor and extensor tendons to be bound fast in the callus of the proximal or middle phalanx, accounts for the great disability from finger fractures If there is no displacement the tendons seldom adhere, but they will in presence of displacement and especially if an outjutting fragment of bone is against the tendon If the fracture unites with backward angulation, the finger will be robbed of that same angle of flexion in making a fist. If there is rotary displacement the finger flexes in the wrong plane.

Treatment. Treatment of fractures of the proximal and middle phalanges is by the same method of nonpadded plaster casts including the forearm, and by the soft wire extension holding the fingers semiflexed and under traction, as described for

fractures of the metacarpals. The finger and splint are not flexed together at the same time for fear of necrosis, instead, the finger is set and the splint holds it so. Pulp traction is used, or if there is no displacement and hand. Its palm, just short of the palmar crease, terminates in a cup in which rests a firm ball of gauze. The fingers by pulp traction are drawn around this ball toward the tuberosity of the scaphoid at

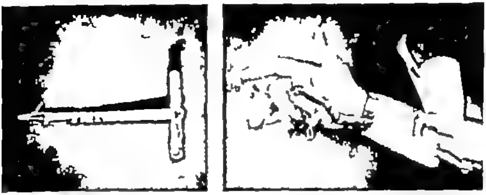


Fig. 592. Traction splint for fracture of metacarpals and phalanges. (*Left*) Made of duralumin for penetration by the x ray the splint is shaped to the hand and wrist as shown at the right. A steel safety pin bent as shown with its point snipped off after thrusting it through the finger pulp serves for traction.

(*Right*) The splint as shown is incorporated in plaster of Paris enclosing the forearm and the hand to the distal palmar crease after the first few layers of plaster are in place.

This is similar to the splint of wire advised by Böhler

spiral adhesive strips, and often even a curved gutter splint without traction, will suffice. For fracture of the proximal phalanx the proximal finger joint is placed at an angle of 45°, the middle 90° and the distal 45°. This places the distal phalanx parallel to the metacarpal. The strong angle at the middle joint aids in traction on the proximal phalanx. A cord connects the end of the extension wire to the cast at the wrist to keep the curve.

The distal fragment should be placed in line with the proximal, using curved splints to keep the fingers semiflexed. If a finger is put up straight, as on a tongue blade or by a banjo splint the fracture will displace and the finger stiffen. If one finger is too straight or too flexed movement of the adjoining digits will be limited. These should be free for full movement by ending the cast at the distal crease in the palm and allowing full movement of the thumb.

A simple method of setting fractured phalanges of several fingers starts with the application of a plaster cast to the forearm

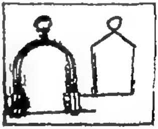


Fig. 593. Traction bows for fingers (Dupuy on left)

which site their traction wires are tied to a hook in the cast. The fingers are in the position of function and are pulled around a pulley just as in the Böhler method.

In setting the fracture one should consider the natural lateral curves of the fingers, which bend slightly toward the long finger. Under traction, in semiflexion the fingers should converge to the scaphoid tubercle. If fingers are pulled parallel or diverging the bones will heal angulated. The nails as guides for the rotation should be each in its correct plane and the plane of motion of the joints should pass through

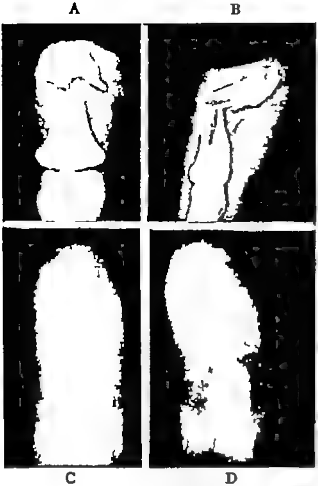


Fig. 594 (A and B) Fractures of distal phalanx.
(C and D) Slipped epiphysis of distal phalanx.

Fig. 596 Deformity with fracture of middle phalanx depending on whether or not the fracture line is proximal or distal to the insertion of the flexor sublimis tendon. This deformity is not constant.

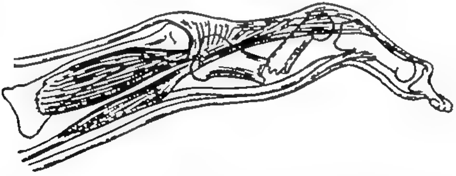


Fig. 595 Deformity with fracture of proximal phalanx is a buckling forward because of the dorsal aponeurosis which is held taut by the intrinsic muscles and the long extensor The buckling is increased by the tone of the long flexor muscles.

the tubercle of the scaphoid. In three or four weeks the union will be firm. Over traction prevents union

Proximal Phalanx The proximal phalanx is frequently fractured across transversely in its proximal half but may be much comminuted or fractured through either of its ends, often obliquely through the head. If the head is fractured off it displaces backward. The deformity in shaft fractures is flexion of the proximal fragment from the interossei and lumbricales flexing the proximal finger joint by their transverse fibers, and dorsiflexion of the distal fragment by the pull of the dorsal aponeurosis through its lateral bands by the intrinsic muscles and its central slip by the long extensor, thus buckling the phalanx volarward There may also be some lateral and rotary displacement

Middle Phalanx. Though usually not displaced it may be buckled dorsally or volarward, depending on whether fractured proximally or distally to the sublimis insertion In the former, the extensor tendon by the insertion at its base extends the proximal fragment, and in the latter the flexor sublimis which attaches at the middle of the phalanx flexes the proximal fragment.

Reduction is by traction, placing the finger on the same curved splint as in fractures of the proximal phalanx and extending the cast well up the forearm The splint should be straight in only *that part crossing a* proximal fracture. A curved gutter splint strapped to the finger may be used if there is no displacement

DISTAL PHALANX Here the fracture is from crushing and is usually comminuted and with injury to the soft parts Rarely, it is across the shaft from angulation There is often the complication of tense hematoma in the closed pulp space, with agonizing, throbbing pain, sometimes from the pressure resulting even in avascular *necrosis of the diaphysis Symptoms from* the latter may flare up two weeks later The pressure should at once be relieved by shaving a hole in the nail by removing the nail for escape of blood, preventing infection by an antiseptic dressing Often the nail is detached or split across giving exit

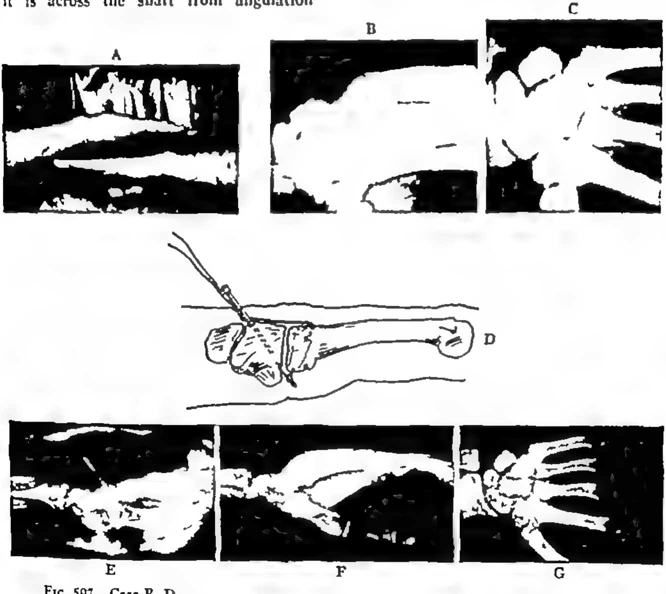


FIG. 597 Case R D

A posterior dislocation of the fourth and fifth metacarpals on the carpus and a fracture of the third resulting from a punch to a chin.

(A) The deformity Muscle balance was upset so the fingers lacked two inches of flexing to the distal crease in the palm.

(B and C) X ray appearance.

(D and E) At operation three months later adhesions were cut away the bones replaced and held there by a withdrawable stainless-steel nail and wire On first withdrawing the nail the wire is easily pulled out. The third metacarpal was wired.

(F and G) Final result was correct approximation and complete motion.

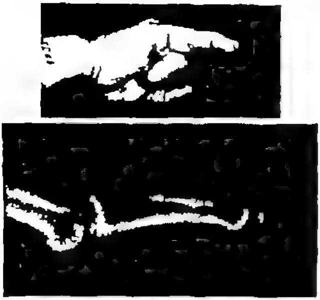


FIG. 598 Case W K., aged 42 While pushing a log the little finger bent backward, dislocating at the middle joint. It was pulled only partially in place and increasing pain followed. In making a fist the finger stands forward straight There was no flexion of the middle joint. The illustrations show the condition six months later

At operation it was found that the whole of the anterior part of the capsule had evulsed from the proximal phalanx and all was sealed by scar tissue. The capsule was resutured in place with removable stainless-steel wire. In two months the joint flexed to 80 voluntarily and 92 passively and the finger flexed to the proximal part of the palm, lacking one-half inch of the distal crease in the palm.

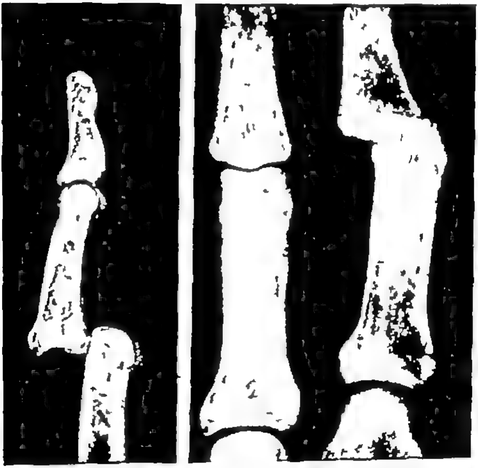


FIG. 599 Dislocation of middle finger joint necessitating open reduction. There will be some permanent limitation of motion if not reduced early

to the blood If merely split, it may be preserved as a splint. If the fracture is comminuted removal of the nail allows drainage, inspection and the removal of loose fragments of bone.

Healing usually occurs after two weeks of simple splinting. If the break is across the shaft healing may be slow, and after comminution a tip of bone may continue to give pain from nonunion until removed.

Stubbing the finger, forcing the distal joint into flexion, often avulses the dorsal margin and rarely has overextension avulsed a volar triangle. Treatment is de ment of bone, causing painful swelling and extra mobility, often of long duration, un less promptly splinted for three weeks Im mobilization on a curved splint stops pain,

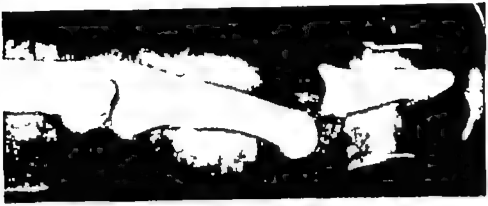


FIG. 600 Dislocation of distal finger joint.

FIG. 601 Two fractures through base of thumb metacarpal, not Bennett's.
Easily corrected by splinting with metacarpal well extended and the wrist in radial and dorsiflexion to relax the abductor pollicis longus.

scribed under rupture of tendons, in Chapter 9

OPEN FRACTURES. The wound should be promptly débrided, explored, and the bone set. Unattached fragments should be removed and, unless in distal phalanx, pulp traction is established The wound may be closed or packed open as indicated. If infected, see Chapter 14 for treatment.

FINGER SPRAINS

Overangulation of such snugly fitting joints as the interphalangeal ruptures part of the capsular ligament or avulses a frag

and the ligament promptly heals. Otherwise for many months there will be tenderness, disability and stiffening of even the adjoining fingers Some swelling and slight deformity may remain The lateral and dorsolateral ligament is often torn, or there may be a dislocation and immediate reduction affecting the whole capsular ligament. From hyperextension of the middle joint, the glenoid ligament or anterior part of the capsule may rupture. This heals, if not splinted, with such thickening and shortening that a flexion contracture results which to remedy defies surgical skill If

Fig. 602 Case W H.
(*Top*) Fresh Bennett's fracture with loss of hook and dislocation
(*Bottom*) Same corrected by skeletal traction for five weeks.
An excellent result was obtained.

severely ruptured the deformity may be hyperextension of the middle joint and flexion of the distal

DISLOCATIONS

Dislocation of Metacarpals on Carpus

The metacarpals of the finger are firmly fixed to and move with the distal row of carpal bones, the thumb moving with the proximal row Force applied through this region usually produces dislocation through the carpus or fracture through metacarpals or carpals though occasionally, from the direct force of machinery, one or several metacarpals may dislocate backward or forward on the carpus. Reduction is easy if

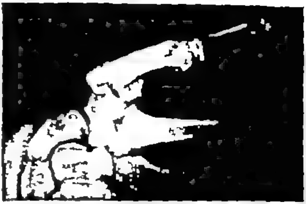


Fig. 603 Bennett's fracture with considerable dislocation of the main fragment.

early, but if late requires open operation and traction Reduction is necessary to restore muscle balance and proper mechanics.

Dislocation of Phalanges

Proximal finger joints dislocate rarely and in any direction Usually dislocation is of the index finger and from hyperextension, and the head of the metacarpal may be caught in the hole of the anterior capsule, as in the thumb The middle and distal finger joints dislocate more frequently, the distal phalanx of either joint displacing back over the proximal one Reduction under local anesthesia by traction is usually easy, and three weeks of splinting at 45° of flexion allow prompt healing of the ligaments and recovery, a curved gutter splint being used The material may be aluminum, sheet lead, celluloid, Castex, plaster, or plastics Later, until the soreness leaves, the joint can be braced by wrapping about it four layers of adhesive plaster

Some dislocations cannot be reduced without an open operation It will be found that from hyperextension the head of the proximal bone has thrust through a hole in the anterior capsule and there caught, so the capsule prevents reduction Through a lateral incision the hole is seen, and when enlarged longitudinally the head of the bone slips back into place If done after two weeks the capsule will be so organized by granulation tissue and scar that the joint

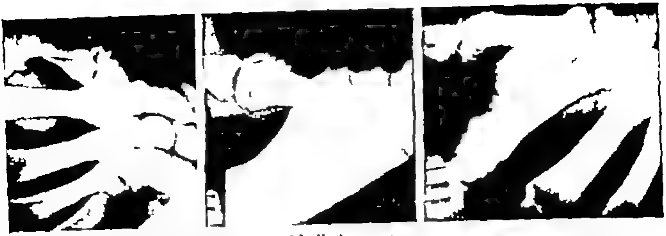


FIG. 604 (*Left*) Bennett's fracture with displacement.

The loss of the hook action of the metacarpal on the greater multangular allows backward dislocation.

(*Center*) Anteroposterior view

(*Right*) By skeletal pin traction through the head of the metacarpal the hook united in perfect position, thus preventing dislocation

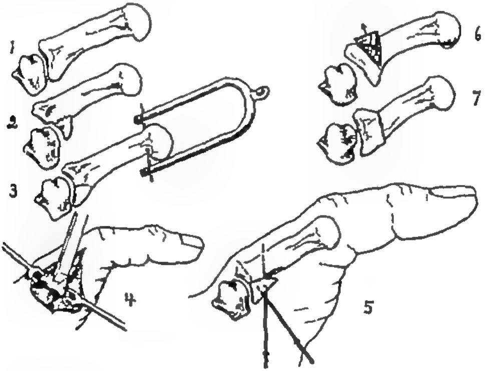


FIG. 605 Treatment of Bennett's fracture with dislocation, primary and late.

(1 2 and 3) For fresh fracture skeletal traction and plaster cast are used.

(4 and 5) For moderately late case not reduced, through an L incision stripping muscles from metacarpal, the piece is chiseled off and replaced. Position is maintained by stainless steel pins through the skin and a plaster cast.

(6 and 7) For old case backward dislocation is prevented by reestablishing the restraining hook of the metacarpal by a wedge osteotomy

will be permanently stiff In the proximal joint of the index finger the sesamoid bone has caught between

In some interphalangeal dislocations it will be found that the anterior capsule has avulsed from the bone either proximally or distally and is turned in between the two bones. In an old case, it and the lateral ligaments may be found so thickened as to need excision In others, the free distal

FIG 606 (*Top*) Three months previously received a Bennett's fracture as he braced his hands against the front seat in a *head-on collision. There is displacement* of the hook and dislocation causing pain and crepitation on gripping.

(*Bottom*) By open operation the hook fragment was chiseled off replaced, and held so with two stainless-steel pins penetrating the skin. Another passing through the greater multangular keeps the dislocation reduced The result was freedom from disability

edge of the anterior capsule can be reattached to the phalanx by catching it in a loop of stainless steel wire passed through a drill hole and on out the dorsal skin to be tied over a button Maintenance of reduction is then easy The final result will be some limitation of movement.

INJURIES OF THUMB

The thumb is so important that whatever *the injury we should salvage every portion* rather than amputate. Any of the bones of the thumb may be fractured, and any of its joints sprained or dislocated. Fractures of the phalanges are treated the same as of the fingers. In the proximal phalanx, the thenar muscles by their attachment to the base draw the proximal fragment into flexion and adduction, thus buckling this phalanx volarward, so the distal fragment must be put in line with the proximal one, using a curved splint or a roll of bandage in the palm.

Metacarpal Fractures, Thumb. Fractures of the first metacarpal are largely of two types the one transverse and near the base being easy to treat, and that through the carpometacarpal joint being difficult. In the former, the strong abductor pollicis longus cocks back the proximal fragment and the thenar muscles and long flexor angulate the distal one volar and ulnarward. In reduction, the metacarpal is grasped and forced into alignment with the proximal fragment, which is abducted The metacarpophalangeal joint is allowed to flex so as to relax the long flexor tendon, and the wrist is supinated and dorsiflexed to relax the abductor pollicis longus The angle between the first two metacarpals should be kept wide. Position is easily maintained by a nonpadded plaster cast, including the forearm and reaching to the distal joint of the thumb

Fracture Dislocation of Metacarpal Through Carpometacarpal Joint (Bennett's Fracture) Occurring from a fall, or often in boxing the metacarpal is so forced into flexion that a triangular piece, including half of the joint surface, is pushed *off from the anterior margin by the greater* multangular The small fragment tips and remains in place, while the rest of the metacarpal displaces backward and proximally on the carpal bones. Callus fills in between the two fragments, uniting them. Hence, the name stave fracture, from resemblance to a forked staff, such as associated with the medieval monks.

This fracture is quite disabling from malunion and later arthritis. The joint remains tender and swollen, the grasp weak, in pinching there is pain, and the metacarpal is *felt* and seen to dislocate backward The reason for this is that normally the projecting volar lip of the base of the metacarpal hooks in front of the greater

multangular, preventing backward dislocation of the metacarpal. When fractured off and reunited, tilted and with the metacarpal displaced proximally, this hook effect is gone and there is nothing to check the backward dislocation This to-and fro extra mobility is easily demonstrated

TREATMENT This fracture, being oblique, will not hold its set in a cast, nor is skin or pulp traction strong enough to maintain anatomic position of the bone so that the hook effect is reestablished These methods are uniformly ineffectual Pin traction through the metacarpal head will

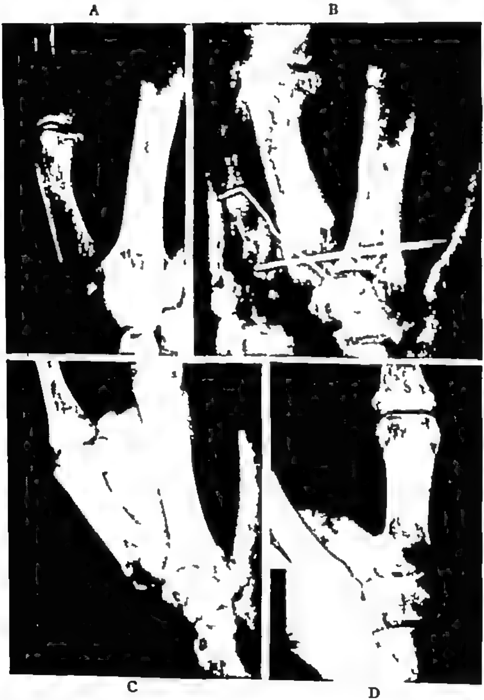


FIG. 607 Case S C.
(A) Unreduced Bennett's fracture of a month's duration, caused by striking with thumb There is displacement of the hook, allowing dislocation.
(B) Open reduction was done, holding the fragment by two stainless-steel pins and the bone from dislocating by another
(C and D) Hook is reestablished, preventing dislocation. There is freedom from symptoms.

Fig. 608 Case A. C. Osteotomy for malunited Bennett's fracture Three months ago he fell with his hand striking a concrete floor. He complained of pain on pinching with the thumb or making a fist, and could not bear the jar of using a hammer

(*Left*) The metacarpal dislocated freely as the hook effect of the metacarpal on the greater multangular was lost.

(*Center*) The metacarpal was angulated backward by a wedge osteotomy at its base to restore the hook effect.

(*Right*) Final result. The hook and dislocation are corrected. He is free from disability though the tip of the thumb lacks one-half inch in flexion and adduction of reaching as far as does his other thumb.

Fig 609 Arthrodesis between thumb metacarpal and greater multangular with position maintained by a stainless-steel pin through the skin The joint was painful and arthritic from an old unreduced Bennett's fracture.

X-ray views before and after the arthrodesis.

FIG. 610 Case W G
(*Left*) Bennett s fracture and dislocation. Unreduced reset by open operation two months later.
(*Center*) Stainless steel pins used to hold fracture and dislocation in place. One pin only projects through the skin.
(*Right*) The fragment was replaced enough so excellent function was obtained.

readily restore perfect anatomic position. A nonpadded cast should include the forearm and hold the wrist in radial flexion and supination. It should press firmly and flatly forward against the back of the metacarpal base, to prevent dislocation backward. Projecting from the cast is a rigid wire extension for attachment of the skeletal traction, with the thumb in the direction of extension Immobilization of four to six weeks is required. The criterion for satisfaction is the reestablishment of a good hook.

An excellent method is to hold the fragments in anatomic position by pinning with removable Kirschner wires The fracture is set manually by traction and pressure The pins penetrate the metacarpal longitudinally and obliquely into the great multangular bone The wires are cut off beneath the skin, and a cast is applied to prevent movement

In old cases of disability from malunion, several methods are available, each of which I have found to give good results

Arthrodesis, wedge osteotomy, and chiseling apart and refastening the fragments in place with three stainless steel pins. In arthrodesis, there will be sufficient motion for the thumb by its other joints In osteotomy, a wedge is removed with its base dorsally, so the metacarpal bends backward after union. Then when the metacarpal is again flexed, the hook effect will be reestablished (Figs 605 and 608) In the open pinning of the fragment, two pins hold the fragment to the metacarpal and one through the greater multangular and metacarpal prevents dislocation The pins are later withdrawn An excellent exposure is afforded by incising along the dorsum of the metacarpal and turning volarward at the wrist to follow the flexion crease The muscles attached to the metacarpal are stripped off volarward and replaced

Dislocation of Carpometacarpal Joint. Dislocation backward of this joint may occur without Bennett s fracture If seen early immobilization in reduction in a nonpadded plaster cast is sufficient, l case needs surgery either to arth

FIG. 611 Case H. H. M.

(*Top* and *Center*) While resting the hand on a railing three months previously the base of the thumb was forced volarward, dislocating the first metacarpal, rendering the carpometacarpal joint unstable.

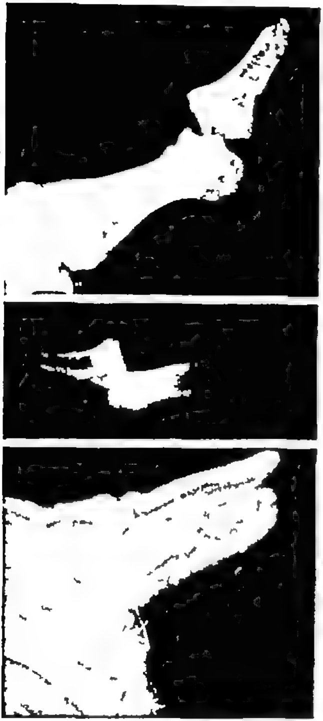
(*Top*) Shows instability of joint there being dislocation volarward. There was soreness and pain on gripping on using the hand. First two metacarpals are wide apart.

(*Center* and *Bottom*) At operation the débris was cleared from between the bones and the metacarpal replaced. The first and second metacarpals were each drilled from front to back and through these a tendon graft from the palmaris longus and a No. 28 stainless steel wire were used to lash the bones together The latter was to hold the bones in place until the graft was well established. The wire was placed so it could be removed in three weeks. A good result was obtained with freedom from disability

A

B

C



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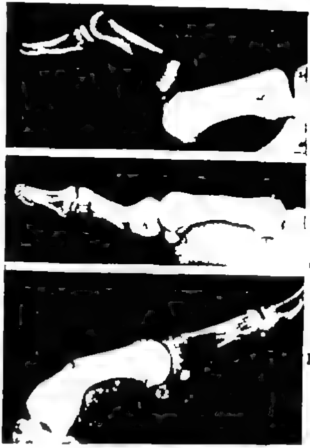

FIG 612 Injuries of thumb
(A and B) Dislocation of distal joint.
(C) Dislocation of proximal joint with usual deformity (in child) (D) Dislocation of proximal joint with usual deformity (E) Usual angulation in fracture of proximal phalanx. (F) Usual angulation in fracture of metacarpal.

joint or to lash it in place by a free tendon graft placed through drill holes. Through a curved incision following the radial flexion wrinkles of the wrist, the twigs of the radial nerve and the artery are retracted backward, the bones are exposed between the tendons of the extensor pollicis longus and brevis The palmaris longus tendon or a strip of fascia lata are so placed as to lash the metacarpal volarward on the greater multangular (Fig 270) Passing laterally through a drill hole in the metacarpal from the radial to the ulnar side, the graft is drawn through and made to enter an anteroposterior hole in the greater multangular from volar to dorsal, emerging between the two dorsal prominences of that bone It is then passed with a Deschamps carrier around under the oblique ridge of the multangular, back to be fastened to its other end at the metacarpal Arthrodesis is usually preferable. See page 309

Injuries of Metacarpophalangeal Joint. SPRAIN From lateral sprains of the thumb, the lateral ligament on the ulnar side may rupture, or more commonly that on the dorsoradial side, causing pain swelling tenderness and abnormal mobility, and pain and weakness on pinching If recent, a month of splinting will cure, but if old the capsular ligament should be sutured and reenforced by a graft of strip of fascia lata well contacted to the bone.

A strain of the insertions of the adductor pollicis muscles causes pain on pinching It may be splinted by wearing a narrow web belt and buckle passed with one loop about the hand crossing in the cleft of the thumb, and the other loop about the thumb

One of the two sesamoid bones in the anterior capsular ligament of this joint of the thumb may from direct violence be fractured across, giving soreness for several months. Eventually, the bone unites. A bipartite sesamoid may be confusing.

Dislocation of Metacarpophalangeal Joint From overextension the capsular ligament yields and the head of the metacarpal is shoved through the base of the anterior or glenoid ligament between the sesamoid bones and the tendons of the two heads of the flexor pollicis brevis. The proximal phalanx displaces backward until it stands at a right angle to and with its base resting on the dorsum of the metacarpal. The external collateral ligament is usually also ruptured, making the dislocation somewhat ulnarward, as well as backward The two sesamoids are joined by the strong transverse glenoid ligament, and this unruptured, and sometimes with one of the sesamoids, lies across the back of the metacarpal head, interposed between it and the phalanx to prevent reduction

Reduction may be easy if done early and if one is mindful of the peculiar mechanism The proximal phalanx is grasped as it stands at a right angle back of the metacarpal It is shoved at this angle distalward, wiggling it in rotation so as to work the capsule over the head of the metacarpal until the joint flexes and snaps into place It is immobilized in flexion for a month If insufficiently reduced, it may recur, thus giving limitation of grasping power

Open reduction may be necessary, in which case through a lateral incision the anterior capsule is slit longitudinally sufficiently to extricate the metacarpal head. If the joint is too disintegrated, it may be fused without great loss of function

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14

Infections of the Hand

PYOGENIC INFECTIONS

General Considerations

A big fire may start from a little match, and so it is that from a tiny scratch or puncture there may result a terribly infected hand and arm. Gross injuries of hands receive prompt surgical treatment, thus usually avoiding infection. Most badly infected hands give the history of a trifling injury, the treatment of which was neglected, the patient having continued work, reporting only late after the infection was well under way. Infections of hands cause much unnecessary crippling, adding greatly to the expense of compensation cases and to the time lost from work. Of the disability from injured hands perhaps one third to one-half can be ascribed to the factor of infection. From such a minor injury as a scratch, an infected callus, or a tiny puncture through one of the flexor creases of a finger or thumb, virulent germs may rapidly invade a hand traveling through lymphatic vessels or deeply through synovial sheaths until this whole complex structure, so valuable to the worker, is wrecked. The devastating effect on the tissues has been described in the preceding chapters.

Infection still makes its quota of crippled hands but due to the medical profession's better understanding of the treatment far better results are being obtained. Fortunately, we now seldom see the tremendously swollen, infected hands and forearms that were so common 25 years ago, just as were the huge pus tubes which are now also rare. Multiple incisions were made in those hands, but from lack of understanding the deep collections of pus were not reached, and by wrongly placed incisions other spaces became infected.

Prevention of Infections

In industrial plants employees should be instructed by lectures and posted signs that on receiving even an insignificant injury they should report to the trained first aid man or nurse. With this system, little time is lost from work and the wound early receives its proper cleansing and the protection of a dressing. Half strength tincture of iodine reduced infections by one-half until replaced by washing, débridement and penicillin. The first may be the only dressing necessary, but if the case requires more it should at once be sent to a doctor.

All machinery should be guarded and the plant should be inspected frequently for any projecting point or edge that can scratch or otherwise produce injury. There should be a daily record of the source of every injury and infection and a follow-up system to correct the cause and prevent recurrences. Individuals repeatedly injured should be transferred away from machinery.

Infections in General

So much has been written on infections of the hand that in this chapter I shall attempt to make only a brief outline of the subject as a practical guide. By the close of the last century, considerable was known

about the spaces and tendon sheaths of the hand in their relation to the pathways of extension of pus, as is shown by the following quotations from Sir Frederick Treves and Sir Arthur Keith as published in 1901 in their little book, Applied Anatomy

The Fasciae The structures of the palm are divided into three spaces by the fasciae Thus the muscles of the thenar and hypothenar eminences are both enclosed in a thin fascia proper to each. The two spaces formed by these membranes are enclosed in all directions and are capable though only in a feeble way of limiting suppuration when it commences in them. Between these two spaces is a third space which is roofed in by the palmar fascia. This cavity is closed in at the sides, but is open above and below Above there is a free opening beneath the annular ligament and along the flexor tendons into the forearm while below there are the seven passages provided for by the division of the palmar fascia. Of these seven passages four situated at the roots of the several fingers give passage to the flexor tendons, while the remaining three correspond to the webs between the fingers, and give passage to the lumbricales and the digital vessels and nerves. When pus, therefore, forms on the palm, beneath the palmar fascia, it cannot come forward through that dense membrane, but escapes rather along the fingers or makes its way up into the forearm So rigid is the resistance offered by the palmar fascia, that pent up pus will make its way through the interosseus spaces and appear on the dorsum of the hand, rather than come through the coverings of the palm. The passage of pus, however, towards the dorsum is resisted by a layer of fascia that lies deeply beneath the flexor tendons, and covers in the interossei muscles, the bones and the deep palmar arch. This fascia joins on either side the fasciae enclosing the thenar and hypothenar "spaces."

Synovial Sacs and Sheaths There are two synovial sacs beneath the annular ligament for the flexor tendons, one for the flexor pollicis longus, the other for the flexor sublimis and profundus tendons. The former extends up into the forearm for about 1½ inches above the annular ligament, and follows its tendon to its insertion in the last phalanx of the thumb The latter rises about 1½ inches above the annular band, and ends in diverticula for the four fingers. The process for the little finger usually extends to the insertion of the flexor profundus tendon in the last phalanx. The remaining three diverticula end about the middle of the corresponding metacarpal bones. The synovial sheaths for the digital part of the tendons to the index middle and ring fingers end above about the neck of the metacarpal bones and are thus separated by about ½ to ¾ inch from the great synovial sac beneath the annular ligament Thus there is an open channel from the ends of the thumb and little finger to a point in the forearm some 1½ inches above the annular ligament. The arrangement explains the well known surgical fact that abscesses of the thumb and little finger are apt to be followed by abscesses in the forearm while such a complication is not usual after suppuration in the remaining fingers. The synovial sac for the flexor tendons is narrowed as it passes beneath the annular ligament, and thus it happens that when distended with fluid or with pus, it presents an hourglass outline, the waist of the hourglass corresponding to the ligament. The two synovial sacs beneath the ligament sometimes communicate with one another

A few years later, Kanavel injected the sheaths and spaces, establishing the present conception of the thenar space and its division from the midpalmar space and made careful clinical study of hand infections. By his book, Infections of the Hand, and other writing he systematized the subject, contributing much in educating the profession in the treatment of infections of the hand Further contributions to our knowledge have been made by Klapp and Beck, Koch, Mason, Iselin, Grinnell, Auchincloss, and others, so the subject at this stage of our progress has been fairly standardized.

The hand is divided into many compartments Some are separate and others are connected by passageways to still other compartments, so that infection and pus may spread in a serial manner from one to the other Thus in some locations the pus will point to the surface and in others it will travel through certain channel spaces or sheaths from a digit to up the center of the forearm. It is usually not difficult to diagnose the site of pus and to open the correct space. If we open the wrong one, we infect it. By correct treatment most infections can be stopped promptly Subcutaneous and fascial space infections usually heal without disability, but infections of

joints or tendon sheaths leave, as a rule, some crippling When the virulence of the germ is high, as in some infections in doc tors and nurses—especially lymphangitis—the infection may, if given a start, travel like a fire in a *prairie, even to the fatal* issue. Fortunately, the sulfa drugs and penicillin are now available. They promise great aid in treating infections. Never, however, should we so rely on chemotherapy that we forget the fundamental surgical principles Infections of the hand today will be as bad as they ever were if un aided by the benefit of modern knowledge

Special Entities

Felon

A felon is an abscess in the pulp space of a digit. The distal segment is divided by a fibrous, oblique diaphragm The pulp space including the distal third of the dia physis is anterior to it, and the epiphysis, proximal two-thirds of the diaphesis, and nail posterior When infected by extension or puncture the pus gradually fills and distends this closed space under pressure, *pressing* off the blood supply to the tip of the diaphysis, but not that to the two-thirds of the diaphesis and sis which is from vessels from the

ment. Therefore, the tip, a border, or the *distal part of the diaphysis sequestrates*, but the epiphysis is usually spared In severe felons unrelieved, the epiphysis and distal joint are also destroyed.

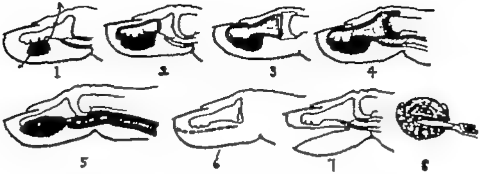

Fig. 613 Felon, extensions and drainage.
(1) Simple felon points posteriorly or anteriorly
(2) Diaphysis has sequestrated.
(3) Diaphysis and epiphysis involved.
(4) Extension into distal joint.
(5) Extends through tendon sheath, tenosynovitis.
(6) Location of incision in one side only
(7) Alligator-mouth incision for severe involvement.
(8) Incision in cross-section intercepting vertical columns.

*Symptoms. One or two days after in*fection the distal segment is swollen, indurated, and with such severe throbbing pain that sleep is impossible. Temperature is raised one or two degrees, though the pulse only slightly After several days the pain lessens, due to necrosis.

Treatment. Under general anesthesia the pulp space should be widely opened with a bloodless field. The space is traversed by multiple vertical, irregularly longitudinal septa from skin to periosteum, so in spite of a vertical midline incision the pus will, instead of draining, point dorsally proximal and lateral to the nail Therefore, the incision should cut across these columns to drain all It may be made along one side and just around the tip which is usually sufficient, but in bad cases the alligator mouthed incision dorsal to the tactile part of the a gauze strip laid across throug better drainage. This incision airly near the nail to be away fr e surface and should, as soon as , be dr together to

avoid a gutter scar If one forms, it can readily be corrected later by excision and smooth closure.

Only a thin membrane separates this abscess from the lumen of the tendon sheath, and sometimes pus perforates through this precipitating thecal infection. Care must be used in incising not to cut through into the sheath. The sequestrum of the dia physis is removed if loose, or its necrotic part can be nibbled off and penicillin applied locally If the epiphysis is intact and the sequestrum be left for two weeks before removal, the bone will regenerate. If the joint is infected and the infection is progressing rapidly, the distal segment should be either amputated, leaving the flaps open or else after weeks of dressings the distal joint can be expected to be permanently stiff

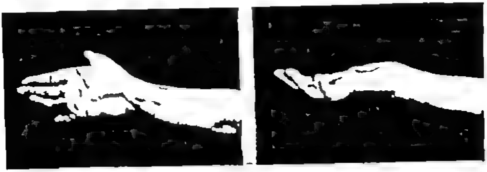

FIG. 614 Hand wrecked by infection starting in pulp of thumb and drained by a few tiny incisions For three weeks the temperature was high and it took four months to heal Infection up sheath of thumb flexor through the radial and ulnar bursae and down the little finger Midpalmar thenar and forearm spaces became involved. Bare bone was present in the thumb. Tendons and nerves sloughed Joints stiffened in positions of nonfunction.

Paronychia

Starting from a hangnail or a manicurist's unsterilized instrument, infection commences in the paronychium at the side of the nail At this early stage of local redness, swelling, and pain, mere separation of the fold from the nail or a small incision from the depth of the sulcus outward, letting out a drop of pus, is sufficient to cure Untreated, the pus follows around the base of the nail under the eponychium, and at the angle infects that potential space, the ungual bursa beneath the nail where the loose attachment corresponds to the lunula.

Treatment. If just commencing, clipping out the corner of the base of the nail and packing the fold open will check the infection, but when it fulfills its name of "runaround," the base of the nail clear across, including the lunula, should be removed by cutting across with pointed scissors and lifting or slightly pulling away the base, which may be already loose The fold should then be kept packed widely open with penicillin ointment gauze, not tight to erode from pressure but gently with the flat end of a probe.

Only if the paronychia is severe should the two cuts be made, one at each side of the nail in addition to removing the nail. In presence of a light tourniquet, ethyl chloride spray will give sufficient anesthesia. The knife point is placed at the very depth of the base of the sulcus at the side where the nail curves in sharply, and is then thrust on out through the soft parts, making a dog ear on each side. The whole flap of skin is lifted up and the penicillin gauze tucked in across beneath it. The wound should be epithelized and well in two weeks or else new nail will grow in, acting as a foreign body, again perpetuating the infection.

The base of the nail infolds the skin as the matrix. This should never be cut, for

the nail will grow ridged, catching on clothing at its free edge

Chronic cases may be cured by merely keeping the fold packed open or by removing the nail base and starting anew If intractable, one suspects trichophytosis, moniliasis, or syphilis.

Carbuncle

This occurs in the hair-bearing areas on the dorsum of the wrist, hand, or proximal segments of the digits. The infection caused from rubbing the nose, mouth, or other source into the sebaceous glands is aggravated by squeezing and spreads beneath the skin involving vertical columns in carbuncle fashion.

Treatment. In addition to the stellate incision to as far as the borders of the induration, each flap should be undermined to cut the vertical columns.

Subcutaneous Abscess

Treatment. On the dorsum, frequently in the proximal segment of the digit, an acute infection occurs deep beneath the

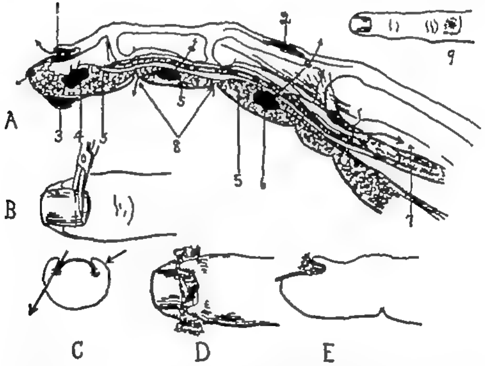

FIG. 615 (A) Diagram of locations of abscesses and where they point.
(1) Paronychia. Perforates base of nail, preserves matrix.
(2) Subcutaneous disk of septic necrosis.
(3) Phlyctenular abscess indicative of felon beneath.
(4) Felon.
(5) Three fat pads of a finger separated from each other by the flexion creases which act as barriers to pus.
(6) Abscess in fat pad. May perforate posteriorly through skin, proximally to subcutaneous tissue in palm or by lumbrical canal to palmar space (7)
(7) Palmar space.
(8) Puncture wounds in the flexion creases are dangerous as they lead directly into the tendon sheath.
(9) Method of draining abscess (2) The transverse arm of incision blocks upward extension.
(B) Treatment of paronychia. The proximal part of the nail is cut across and removed Two lateral incisions are made so as to raise a dorsal flap.
(C) The knife cuts like the large, not the small arrow to drain the pus at the depth of the sulcus.
(D) Gauze with sulfonamide ointment is laid across under the flap.
(E) The gauze should pack into the bottom of the angle but not tight enough to cause necrosis.

skin. It is best incised promptly with an L-shaped incision, the L partially enclosing the indurated area, with one arm of the L reaching across its proximal border so as to block infection traveling up the hand On raising the triangular flap of skin a disc shaped area of green necrosis is uncovered and excised

In the volar aspect of a finger there are three fatty pads, separated from each other by the three transverse volar creases which are free from fat and are attached to the tendon sheath. A subcutaneous abscess in any of these pulp spaces is limited by the creases. There may be a superficial blister like pus pocket, and on excising its lid a communication may be found to the deeper abscess, the two having the shape of a shirt stud. Infection in the middle pulp space may point out the side of the finger or may infect the tendon sheath. A subcutaneous abscess in the proximal pulp space may point at the side or dorsum of the finger, may infect the tendon sheath, or may pass around the side of the proximal crease, which is attached deeply only at its center, and enter the web space Rarely does it extend into the palm unless by the tendon sheath.

The pulp space should be opened at the site of the abscess, being careful not to cut or closely parallel the volar digital nerves and vessels.

Infections from Human Bites

Mouth organisms produce foul, progressive anaerobic infections and are usually introduced into the proximal finger joints by striking the teeth with the fist. The infection is commonly mixed, there having been found not only the usual combination of *Bacillus fusiformis* and the spirochetes of trench mouth but many forms of *Streptococcus* (*viridans salivarius*, and *hæmolyticus*) and also Staphylococcus, *B coli* diphtheroid bacilli and *B proteus* These severe progressive infections are distinctive for three reasons the organisms are human acclimated, the tissues infected are ligamentous and, therefore, of low resistance, and the region is peculiar in that there radiate from it many fascial planes and passageways along which infection spreads to various parts of the hand and fingers Mason and Koch have made a careful study of these pathways of extension

Pain and swelling commence in one to two days, sometimes accompanied by lymphangitis In a few days a foul odor is noticeable and the inflammation extends It spreads not only in the subcutaneous space but in the subaponeurotic space over the dorsum of the hand and distally over the proximal phalanx. The joint itself is usually infected Through the soft fat laterally infection extends into the web space, and by following along the interosseus and lumbricalis muscles or breaking through the anterior surface of the joint the mid palmar or thenar space becomes involved, but only occasionally the sheath of the flexor tendons From the joint infection osteomyelitis affects the metacarpal or proximal phalanx, eroding them rather than involving them massively The infection may terminate in from one to several months, but even after healing there may be periodical flare-ups for even a year and a half

Treatment. Treatment should be prompt and radical, consisting of excision and washing of the wound to its full depth in fist position so the openings will superimpose. Into the cavity, including the joint if penetrated, penicillin solution should be instilled four hourly A little zinc peroxide may be added Bates reported excellent results from making the excision with the cautery Considering the potential danger from such a wound, repair of tendon or joint capsule at this time is dangerous. These measures, combined with immobilization, elevation, warmth, penicillin locally (diluted powder of calcium salt) and penicillin and sulfonamides systemically should prevent infection. If infection is already established the necrotic tissue should be

excised and the above carried out with ample drainage.

By vigilance, extension of infection along the various known pathways can be checked by prompt incision. Infections of this character will readily cross fascial planes and extend by contiguity. Untreated cases are dangerous, even causing death or necessitating amputation of the arm. In advanced cases with necrosis the finger should be amputated through the proximal joint and the wound left wide open. Even with efficient treatment the proximal finger joint will be limited in motion or become ankylosed.

Three Main Forms of Infection in Hand

Pathways and Types

There are three systems of pathways of infection that are largely distinct from each other, though sometimes combined. One is infection in fascial spaces, another is through tendon sheaths, and the third is through the lymphatic system.

Fascial space infections are more numerous, but not nearly so crippling or severe as synovitis, and are more localized. Synovitis accounts for the severely crippled hands, finger joint and wrist joint infections, osteomyelitis, extensions up the forearm, flexion contractures, and some amputions or even deaths. Infections in the lymphatic system are rapid, highly toxic, and often lethal.

Each form of infection usually runs true to type, but may show complications in one of the other systems. Thus, infection may spread from space to sheath or vice versa, and from the deep lymphatics to the sheaths or fascial spaces.

Diagnostic Generalities

When pus is present there is woody hardness, in contrast to the soft edema of general infection. Over an abscess the skin may, from stasis, be violaceous at first, but later show pallor, indicating ischemia before rupture. There is usually more swelling on the dorsum of a hand, because of the loose tissue, even though the infection is volar. One should refrain from incising the dorsum unless the pus is actually there.

Infections can be accurately outlined with ink by pressing with a blunt point, each time starting away and working toward the tender area. The point of maximum tenderness is important. Other localizing aids are the feel of the skin, the local heat, the thickness due to edema of the fold of the overlying skin one pinches up, and the pain on movement of the joint in the vicinity. If tendons pass through an infected fascial space, movement of them is painful—acutely so if through a sheath under tension.

Pain and tenderness are great early in an infection, but later as the nerves become numb or the tissues necrose it may lessen or leave. It is greatest when the pus is under pressure and lessens as rupture occurs into another space. High temperatures mean great absorption from infection in lymphatics, in a joint or a thrombus, or when under pressure. With the advent of specific antibiotics a smear and culture should be made in any serious or resistant case.

Infections in Fascial Spaces

Web Spaces. Filled with loose fat that bulges between the divisions of the palmar fascia at the web interspaces are three small, triangular regions between the volar and dorsal skin. The space, when filled, straddles over the edge of the deep transverse ligament, and though most of the pus is volar the abscess points dorsally.

Infection comes from skin cracks and under calluses that form on the distal fold in the palm, or may extend up from the proximal pulp space or side of the finger. As the front of the space fills there is tender, red bulging in the distal part of the palm and soon it extends dorsally in the

web, giving it the name of collar button abscess. The base of one finger is swollen and the adjoining fingers are spread The pus extends laterally in the distal part of the palm to the adjoining webs. It may

Fig. 616. Collar button abscess.
(A) Palmar fascia.
(B) Posterior compartment on dorsum opposite cleft.
(C) Anterior compartment subcutaneous and filling the web space.
(D) Extension starting beneath tendons toward middle palmar space.

enter a lumbrical canal and extend into the palm or finger

TREATMENT To drain, a curved incision is made about the side and proximal part of the swelling in the palm and also a longi tudinal dorsal one in the interspace.

Middle Palmar Space In the palm is a potential space that when distended is limited as follows

BOUNDARIES.

ROOF — Thin fascia beneath the flex or tendons of the index, long, ring, and little fingers. Part of the ulnar bursa.

FLOOR — Fascia over third and fourth interosseus muscles and fas- cial layers bulging and cov ering the adductor muscles

RADIALWARD — The oblique septum from the third metacarpal span ning to the fascia beneath the flexor tendons and to as far proximal as the carpal ligament. This fascial mem brane is branched, one sheet extending radially to be- neath the flexor tendons of the index finger and on to fuse with the adductor fas- cia This medial septum is proximally so fragile and yielding that it is not a strong barrier against pus It is merely a thin, mem branous continuation of one of the many ligamentous septa that make the distal part of the palm a series of longitudinal tunnels Flynn has demonstrated this partic ular septum in a hundred consecutive dissections of hands. Whether the true radial boundary of the mid palmar space is this fragile septum or the adductor fascia does not seem to be of major practical importance, as it is permeable and readily bulges over the adductor muscles Some authors have considered this space to reach to the first lumbricalis muscle

ULNARWARD — Fascia from fifth metacarpal to over hypothenar muscles.

PROXIMALLY — Tapers to carpal tunnel un der distal border of trans verse carpal ligament. It

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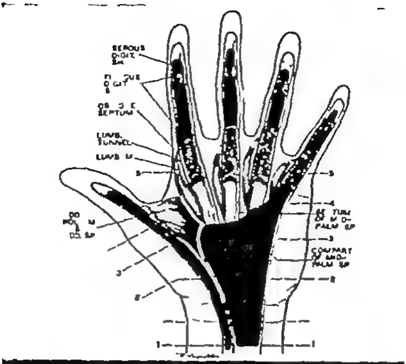
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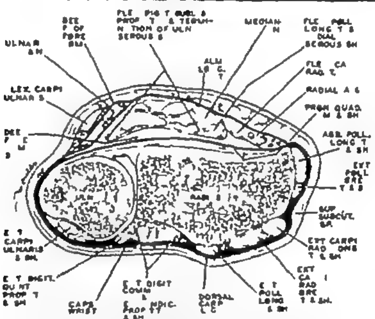
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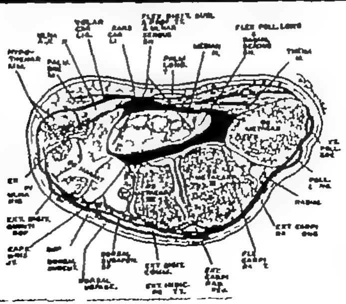
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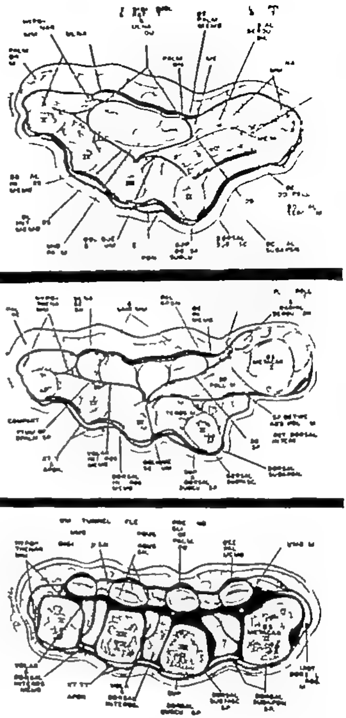

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FIG. 617 Arrangement of fascial spaces and tendon sheaths in the hand

(A) Diagrammatic drawing showing the serous and fibrous (partially) sheaths of the fingers and palm, and their relation to the lumbrical tunnels and midpalmar and adductor spaces. The dotted lines indicate the natural creases and the numbered broken lines indicate the lines of section of (1) to (5) inclusive.

(1) Cross-section through forearm just above wrist showing relation of radial and ulnar serous tendon sheaths to the deep fore arm space (proximal surface)

(Note [1] to [5] inclusive are line drawings made on bleached photographs of serial sections of human material.)

(2) Cross-section through junction of wrist and hand showing relation of radial and ulnar serous tendon sheaths to transverse carpal ligament and capsule of wrist joint (proximal surface)

(3) Cross-section through proximal third of hand, showing relation of radial and ulnar serous tendon sheaths to midpalmar and adductor space (proximal surface)

(4) Cross-section through middle third of hand showing individual compartments of midpalmar space and their relation to flexor tendons and adductor space (proximal surface)

(5) Cross-section through distal third of hand, showing lumbrical tunnels and their relation to flexor tendons and sheaths (proximal surface) (Courtesy Grodinsky and Holyoke Anat. Rec., 79 435–451 April 25 1941)

may communicate here to the thenar space.

DISTALLY Extends down the lumbrical canals of the ring and little fingers

SOURCES OF INFECTION Rupture of cul de-sac of sheath of flexor tendons of index, long, and ring fingers or of ulnar bursa.

Subcutaneous infections of index, long ring, and little fingers, directly or through the lumbrical canals.

Direct infection.

Infection of third, fourth, and fifth meta carpals or proximal finger joints.

EXTENSION TO Points through skin in palm, at base of finger, or on dorsum over web

May involve whole of contents of finger

Rarely extends through carpal channel to forearm.

May extend around base of thenar space.

SYMPTOMS Loss of palmar concavity, or

in contrast to ulnar bursa involvement, even a slight bulge.

Tenderness outline to space.

Palm indurated, distal crease pale from tension.

Swelling and tenderness over lumbrical canal in finger Dorsum of hand swollen

Temperature 100 to 104° F Pain which lessens after a few days.

Middle and ring fingers semiflexed and painful on use. Some pain on straightening as tendons pass over the pus.

Lessened function of interosseus and lumbricalis muscles

TREATMENT Incision through palmar fascia from opposite long metacarpal, paralleling distal crease in palm, to curve proximally down heel of palm near tendons for little finger

Iselin describes a superficial palmar space always secondary to synovitis, between flexor tendons and palmar aponeurosis from distal end of palm to carpal tunnel, through which the infection may extend into the forearm up along the ulnar artery It may point to the web or through the skin of the palm, or extend deep into the midpalmar space.

Thenar Space. Adductor space may be a better name, reserving thenar space for that between the muscles of the thenar eminence which would then be comparable to the hypothenar space (Grodinsky)

BOUNDARIES.

ROOF	Adductor fascia and oblique septum which attaches to third metacarpal posteriorly and extends in sheets to the fascia beneath the flexor tendons, fusing radially with the adductor fascia.
FLOOR	Adductors of the thumb and first interosseus muscle.
RADIALWARD	Fusion of fascia of oblique septum, of thenar eminence, and of sheath over long flexor tendon of the thumb.
ULNARWARD	Septum from third metacarpal and adductor fascia.
PROXIMALLY	Layer of fascia as it tapers to carpal tunnel at distal border of the transverse carpal ligament. Radial bursa is proximal to it.
DISTALLY	Deep fascia under web of thumb

Pus in the thenar space extends around the free border of the transverse adductor muscle to its posterior subcutaneous compartment between the first interosseus muscle and the metacarpal of the thumb

SOURCES OF INFECTION Synovitis index finger and synovitis of the thumb

Subcutaneous abscess index finger and thumb

Osteomyelitis of metacarpals or infected proximal joints of index finger and thumb.

Direct infection

From radial bursa

From midpalmar space.

EXTENSION To Points on dorsum in first interdigital cleft.

Extends down lumbrical canal in index finger and points.

Rarely ascends through carpal canal to forearm.

SYMPTOMS Characteristic great ballooning of web of thumb

Hard, red, tender swelling over radial side of index finger and over first interosseus muscle.

Abduction of thumb and semiflexion of its distal joint. Activation of adductor pollicis brevis against resistance causes pain.

Semiflexed position of index finger and some pain on moving or extending.

Temperature 100 to 104° F and local pain.

TREATMENT Incision on dorsum, curved around radial border of first interosseus muscle. Also, in palm just radial and parallel to the thenar crease, but sparing the thenar motor nerve. The palmar incision may be omitted.

Hypothenar Space This is merely the fascial compartment enclosing the hypothenar muscles. It is unimportant and when infected points dorsally

Dorsal Subcutaneous Space. This is the space between the skin with its superficial fascia and the aponeurotic layer enveloping the extensor tendons on the back of the hand Pus in it may point directly through the skin or about the periphery of the dorsum of the hand.

Dorsal Subaponeurotic Space. This, as its name implies, is between the aponeurosis of the extensor tendons and the hand. It extends down the dorsum of the fingers to each side of the insertion of the extensor tendon. Pus within it points at the webs and the periphery of the dorsum of the hand. From both the subcutaneous and subaponeurotic spaces, pus can extend into the palm through the web spaces.

Quadrilateral Space in Forearm.

BOUNDARIES.

ROOF	*Flexor digitorum profundus tendons and fascia and in proximal part flexor digitorum sublimis muscle.*
FLOOR	Pronator quadratus muscle, interosseus membrane and in proximal two-thirds flexor digitorum profundus muscle.
RADIALWARD	Flexor pollicis longus muscle.
ULNARWARD	Flexor ulnaris muscle.
PROXIMALLY	Upper end forearm, along ulnar artery under pronator teres muscle.
DISTALLY	Wrist.

This space holds a half pint of pus, located deeply beneath the fascia of the flexor digitorum profundus muscles in the lower part, but almost halfway up the forearm where the profundus muscle is broadly attached on the interosseus membrane and ulna the pus rides forward over the profundus and flexor pollicis longus muscles and under the sublimis muscle, becoming superficial in the upper part of the arm between the flexor digitorum sublimis and the flexor ulnaris muscles As the pus extends in front of the flexor profundus muscle it bathes the median nerve and the ulnar artery and nerve, but the radial artery in considerably more anterior

SOURCES OF INFECTION Rarely from the thenar or midpalmar spaces, usually from the radial or ulnar bursa and occasionally from the wrist joint

EXTENSION TO The pus points in the upper part of the forearm between the flexor digitorum sublimis and the flexor ulnaris muscles.

SYMPTOMS General hard swelling in volar aspect of the forearm

Relative swelling as seen from the side, commencing abruptly at the upper border of the transverse carpal ligament.

Not much redness and tenderness, only deep

Pain in forearm which lessens when the nerves become numb or the pus pressure is relieved

The wrist is held flexed and pains somewhat when it is extended.

TREATMENT In the lower part of the forearm a three-inch incision is made just in front of the radius and just in front of the ulna. The radial nerve is displaced dorsally and the dorsal branch of the ulnar volarward. The pus is always deep to the flexor tendons. If the pus extends high in the forearm an incision should be made between the flexor digitorum sublimis and the flexor ulnaris muscles.

Infection in Tendon Sheaths (Tenosynovitis)

Tenosynovitis is serious, and, far more than fascial-space infection, demands immediate incision and treatment. Commencing in the flexor sheath of a digit, the extension upward is rapid and unobstructed If it is in the index or long and ring fingers the pus breaks through into the thenar and

in contrast to ulnar bursa involvement, even a slight bulge.

Tenderness outline to space.

Palm indurated, distal crease pale from tension.

Swelling and tenderness over lumbrical canal in finger. Dorsum of hand swollen

Temperature 100 to 104° F Pain which lessens after a few days.

Middle and ring fingers semiflexed and painful on use. Some pain on straightening as tendons pass over the pus.

Lessened function of interosseus and lumbricalis muscles

TREATMENT Incision through palmar fascia from opposite long metacarpal, paralleling distal crease in palm, to curve proximally down heel of palm near tendons for little finger

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Subcutaneous abscess index finger and thumb

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Direct infection.

From radial bursa.

From midpalmar space.

EXTENSION TO Points on dorsum in first interdigital cleft.

Extends down lumbrical canal in index finger and points.

Rarely ascends through carpal canal to forearm

SYMPTOMS Characteristic great ballooning of web of thumb

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Abduction of thumb and semiflexion of its distal joint. Activation of adductor pollicis brevis against resistance causes pain.

Semiflexed position of index finger and some pain on moving or extending

Temperature 100 to 104° F and local pain.

TREATMENT Incision on dorsum, curved around radial border of first interosseus muscle. Also, in palm just radial and parallel to the thenar crease, but sparing the thenar motor nerve. The palmar incision may be omitted

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SOURCES OF INFECTION Rarely from the thenar or midpalmar spaces, usually from the radial or ulnar bursa and occasionally from the wrist joint.

EXTENSION TO The pus points in the upper part of the forearm between the flexor digitorum sublimis and the flexor ulnaris muscles.

SYMPTOMS. General hard swelling in volar aspect of the forearm.

Relative swelling as seen from the side, commencing abruptly at the upper border of the transverse carpal ligament.

Not much redness and tenderness, only deep

Pain in forearm which lessens when the nerves become numb or the pus pressure is relieved.

The wrist is held flexed and pains somewhat when it is extended

TREATMENT In the lower part of the forearm a three-inch incision is made just in front of the radius and just in front of the ulna The radial nerve is displaced dorsally and the dorsal branch of the ulnar volarward. The pus is always deep to the flexor tendons. If the pus extends high in the forearm an incision should be made between the flexor digitorum sublimis and the flexor ulnaris muscles.

Infection in Tendon Sheaths (Tenosynovitis)

Tenosynovitis is serious, and, far more than fascial-space infection, demands immediate incision and treatment. Commencing in the flexor sheath of a digit, the extension upward is rapid and unobstructed If it is in the index or long and ring fingers the pus breaks through into the thenar and

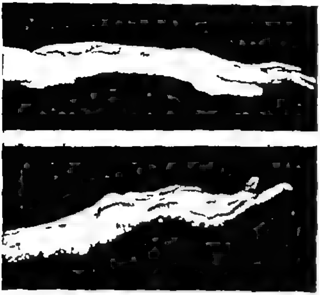

FIG 618 Case G T J Infection in forearm which wrecked the hand.

The forearm was squeezed between a moving ship and a wall, the lacerations being sutured at once Severe infection in the forearm followed resulting in sloughing of nerves and muscles Remains of flexor muscles have atrophied. Hand shows typical atrophy and deformity of paralysis of median and ulnar nerves.

midpalmar spaces respectively, but if in the thumb or little finger there is direct open connection to the radial and ulnar bursae respectively If these fill the pus *may break into the thenar and midpalmar* spaces, or break directly into the quadrilateral space of the forearm From a sheath in a finger the middle finger joint may become infected and from the bursae the wrist joint. This completes the setting for a badly crippled hand.

Etiology *Tenosynovitis results in* most cases from puncture in a volar crease in a digit or infection in a closed pulp space in finger or thumb from direct breaking through at the end of the sheath or from arthritis in the distal joint. At a flexion crease, the skin which is devoid of subcutaneous *fat is attached to the tendon* sheath, which here is very thin for joint movement there being no firm annular ligament about the tendon opposite the joints. At these three vulnerable creases the sheath is readily punctured mostly in the distal crease and in the fewest number the proximal crease. Only second in cause is infection within the pulp space, and here *also the distal closed* space is the commonest and the proximal one the least so Only a few cases result *from infection in the* palm or the dorsum of the fingers and hand. The severe cases start usually in the thumb or little finger

Prognosis. If only one finger is involved and surgical relief is given early before the infection has invaded the tendon *the latter may be saved and regain good* function Too often, however, the tendon is already infected and will then go through a stage of necrosis and either sloughing or reducing to scar tissue. The tendon affected may be damaged to any degree depending on how long pus has been pres*ent and on the virulence of the infection.* If other tendons and joints have been spared the disability may be limited to one finger, with loss of flexion in its distal two joints but with some flexion in its proximal joint.

In half the cases tendons slough out, *from digits or from wrist*, arm, and forearm In the aged they are more apt to slough than in the young, irrespective of whether infected by Streptococcus or Staphylococcus. Segments here of the median and ulnar nerves also slough. Amputation may be resorted to, and a *small* percentage of cases may result in death The wrist joint may escape, and often the infection can be limited by prompt action directed to the sheath or bursa It may be seven weeks to four months before all has healed, tendon and joint infection having prolonged the course The result in a bad case *may be* a congealed hand with flexion contracture flexed wrist, flat hand, thumb at the side and fingers clawed, largely devoid of both motion and sensation Grinnell, in a careful review of 125 cases, reported the following results

13% good results
52% gross tendon necrosis
66% in lower two of four groups

33% poor
0.8% mortality
3 cases amputation arm
3 cases amputation fingers

Iselin, of 20 cases, reports

7 perfect
8 good (one finger stiff)
3 mediocre (ring and little fingers limited)
2 bad (with 40% disability)

Tenosynovitis in a Digit. In the index, long, and ring fingers the proximal cul-de-sac of the sheath ends at the distal crease in the palm, except in about four per cent of cases (Sheldrup). Pus in the index sheath breaks through into the thenar space and from the long and ring finger sheaths into the middle palmar. From these spaces it travels through lumbrical canals to the finger and web spaces, and points dorsally. The sheaths of the thumb and little finger flexors have slight constriction as they are continuous with their respective bursae, radial and ulnar. In rare cases the sheath of the little finger or thumb does not reach the bursa and must rupture into the fascial space, and occasionally the sheath about the ring finger flexor may reach to the wrist. Infection may be limited to only a portion of a sheath if a fibrinous barrier has time to form. Sheath infection in a finger is prone to involve the middle finger joint.

Symptoms. The finger is held rigid and semiflexed; the patient will not allow passive extension because of the great pain, and voluntary attempt to flex against resistance is painful. When, however, the pus breaks through and the tension is relieved the finger may move and can be extended with less pain, and the symptoms subside. Later as the bursa with the median and ulnar nerves is involved, the finger may feel numb. Tenderness can be outlined along the tendon sheath, but it is quite diagnostically maximal over the proximal cul-de-sac of the sheath.

The whole finger and dorsum of the hand may be moderately swollen, though the finger is often not red. The onset is usually fairly rapid. It may be as short as six hours and the temperature may reach 103° F.

Treatment. A prompt midlateral incision should be made from the distal crease

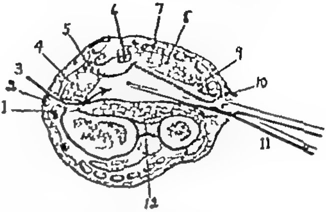

Fig. 619. Quadrilateral space in forearm and cleavage for draining pus when present. Pus collects behind the flexor tendons and in front of the pronator quadratus, and in draining laterally on each side the posterior branch of the ulnar nerve is retracted forward and the radial nerve backward.

Hemostat would expose ulnar bursa for incision.

(1) Abductor longus pollicis
(2) Radial nerve
(3) Drainage radial side and for radial bursa
(4) Flexor pollicis longus
(5) Radial vessels
(6) Median nerve
(7) Flexor digitorum sublimis
(8) Flexor digitorum profundus
(9) Ulnar nerve and vessels
(10) Posterior branch of ulnar nerve
(11) Hemostat in quadrilateral space
(12) Pronator quadratus

of the finger to its base on one side only. Severing the pulleys laterally does not give the bad effects that follow midline severance. Another curved incision, partially paralleling the distal crease in the palm, should drain the cul-de-sac of the sheath. In the thumb the incision is preferable down the ulnar side, so it may be continued a little down the ulnar side of the thenar eminence posterior to the nerve. If a sheath and joint infection are combined, except in the case of a thumb, it may be best to amputate through the joint.

Since the advent of penicillin, tenosynovitis in the first day or before the tendon has been involved, has been cured by instilling into the sheath a solution of penicillin (1000 U per cc.) with preservation of tendon and function. Parenteral penicillin checks swelling beyond the sheath. A tendon is so poor in blood supply that when involved it becomes a sequestrum beyond the reach of penicillin. Surgical drainage should be prompt to prevent tendon damage and extension.

Ulnar Bursa. Description. Under the transverse carpal ligament are two synovial sheaths. One, the radial bursa, envelops the flexor tendon of the thumb and the other, the ulnar bursa, the flexor tendons of the fingers. The two bursae often communicate with each other, so when tenosynovitis is in the thumb or little finger usually both are involved.

The ulnar bursa has invaginated into it from the radial side both the layer of sublimis and that of profundus tendons, so it forms three longitudinal pockets: one in front of the sublimi, one between the two tendon layers, and the third—which is the largest—under the profundus tendons. The mesotenons, being on the radial side, leave the ulnar side free for drainage.

Distally, the ulnar bursa reaches when distended to the distal crease in the palm, and here it is more superficial, thus accounting for the diagnostic tender spot there when inflamed. Proximally, it reaches to one-half inch above the ulnar-carpal joint as a pouch lying on the pronator quadratus muscle. In the palm it partially overlies the midpalmar space, and is beneath some of the hypothenar muscles.

Infections enter the bursa from the sheath of the little finger or the radial bursa, or may come from the thenar space. The bursa usually ruptures in about 48 hours into the quadrilateral space in the forearm and also into the midpalmar space.

When the contents of the carpal tunnel, from infection swell and are under tension, the blood supply is squeezed out of the tendons and nerves and they necrose from the upper part of the annular ligament to the distal half of the palm.

Symptoms. The fingers are held semiflexed, the little the most and the index the least, and they pain on passive extension—especially the little. This is the book sign.

The patient is loath to move these fingers, as the tendons run through pus.

On rupture of the bursa these signs largely disappear.

The hand is large and its dorsum swollen. The hollow in the palm is decreased though present.

Tenderness is outlined corresponding to the ulnar bursa, but is constantly maximal where the bursa almost reaches the distal palmar crease.

The wrist is held fixed and over the bulging, just above the transverse carpal

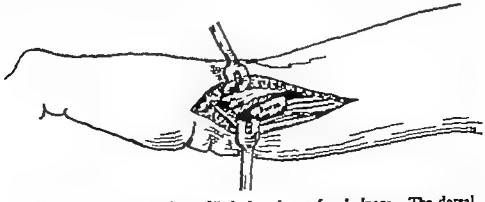

Fig. 620. Exposure of pus filled ulnar bursa for drainage. The dorsal branch of the ulnar nerve and the flexor ulnaris are retracted volarward. The distended bursa is seen between the flexor tendons and the pronator quadratus which covers the bones.

ligament, fluctuation can be felt to the palm.

Temperature is between 102 and 104° F, and the patient looks sick.

TREATMENT The palm and ulnar bursa are opened in a line paralleling the distal crease in the palm and curving at the tendon of the little finger proximally and centrally toward the heel of the palm The ulnar bursa is opened in the forearm by a three-inch incision, just in front of the ulna. The dorsal branch of the ulnar nerve and the flexor carpi ulnaris muscle are retracted volarward. Entering along the pronator quadratus muscle, the bulge of the ulnar bursa is seen and opened. If the quadrilateral space contains pus the radial incision, just in front of the radius should also be made. If the infection is far advanced, it is well to continue the palmar incision proximally, curving it as it crosses the wrist and there lay open, for decompression and drainage, the carpal tunnel at its ulnar side. Median incisions through the transverse carpal ligament are bad as they allow the tendons to prolapse and adhere to the scar, resulting in crippling

Iselin drained the ulnar bursa only in its proximal pouch and the tendon sheath only in its proximal cul-de-sac, and in his 20 cases claimed good results. Perhaps with the aid of penicillin, sulfonamides and other chemotherapy this will become the method of choice.

Radial Bursa. DESCRIPTION The radial bursa narrows at the base of the thumb metacarpal, to be continuous with the sheath of the flexor tendon of the thumb, and reaches proximally half an inch above the end of the radius which is not quite so high as the ulnar bursa. It contains the flexor tendon of the thumb only, and in 85 per cent of cases communicates with the ulnar bursa It is claimed that of the two bursae the radial is more responsible for wrist joint infections.

Symptoms of infection are similar to those of the ulnar bursa, with the exception

FIG. 621 Case A. J B Prolonged infection draining from laceration in palm for six months.

X ray shows sesamoid in wrong location. Therefore, it was removed with forceps as a sequestrum and the wound healed in two weeks.

of the area of tenderness and the fact that the thumb and index finger are affected the most.

TREATMENT The radial bursa can be drained through the same three-inch incision in front of the ulna that drains the ulnar bursa. This has the advantage of providing dependent drainage. The similar radial incision may be superfluous, but can be added in a severe infection or if the quadrilateral space in the forearm is involved. Occasionally, still other incisions are necessary if the infection has spread to other areas.

Osteomyelitis With the exception of compound fracture this is usually secondary to infection in the neighboring tissues. Thus, in the closed distal space in a digit the diaphysis—and if severe and neglected even the epiphysis—become infected, infecting in turn the joint.

From tenosynovitis, infection commonly enters into the epiphysis of the base of the middle phalanx as osteomyelitis, which ex

tends along this phalanx. The middle finger joint becomes infected, and then the head of the proximal phalanx. Osteomyelitis may extend along the shafts of these phalanges so that sequestra separate in three or four weeks. From any infected finger joint osteomyelitis spreads to the two bone ends, at first superficially rather than massively

TREATMENT Wide drainage should be established, including the joint if infected It is best to be conservative, splinting and awaiting sequestrum formation, at which time the sequestrum can be lifted out with assurance that a new shaft will form Nibbling of dead bone is permissible in the distal phalanx, but in the others is apt to cause progression.

In amputating infected fingers, it is best to saw rather than bite the bones off to prevent extension of infection due to cracking the bone.

The Orr treatment was good in its day, but has been superseded by penicillin and surgery Acute hematogenous osteomyelitis yields promptly to penicillin. In chronic osteomyelitis, penicillin prevents spread, thus allowing more radical surgery It acts, however, only on bleeding bone, not when the bone is ebonized or sequestrated When acute infection is over, the infected parts of bones are saucerized, excising necrotic tissue, cicatrix and ebonized bone. Penicillin is given locally and parenterally, the cavity is packed loosely with fine mesh gauze or rayon and, in about eight days, the cavity, if large, may be skin grafted or else allowed to fill by granulations Any bone defect may be filled at a later time excising the skin graft packing with cancellous chips from the ilium and at the same time covering over by local or pedicle skin One loophole for failure is that the bacteria present may be penicillin resistant in which case the sulfonamides or streptomycin may be effective. Another is that not all necrotic bone, ligament or scar tissue may have been excised down to good bleeding tissue Also there may not have been sufficiently good coverage over the bone chips by good skin and subcutaneous tissue so that the wound closed without drainage. Though failures have been reported, in one series of 33 cases in large bones (Banks), success was obtained by this method in 30 cases

Bolder methods sometimes succeed and, also, often break down giving prolonged drainage and extrusion of chips. Coleman excised scar, granulations sequestra and ebonized bone and at once filled the cavity with cancellous bone chips and closed. He reports that, with the help of penicillin there was 92 per cent of healing with obliteration of the cavity in 52 cases

Joint Infection DIGITAL JOINTS If the fever remains high joint infection should be suspected and determined by finding red, local swelling, tenderness in the full circumference of the joint, pain on shoving up the finger through the joint, extra mobility laterally, grating and roentgen appearance of loss of cartilage and contour The distal joint becomes infected from felon, the middle and occasionally the proximal from sheath infection, and all three from direct inoculation.

TREATMENT Infection hangs on in the volar pocket of the joint Two lateral incisions and splinting is the treatment of choice. The Orr treatment of an infected joint results in ankylosis. Excision of the head of the phalanx entering into the joint gives good drainage, but the best that can be obtained is fibrous ankylosis Amputation, except of the thumb, gives a quick solution if synovitis and too many things are wrong with the finger to make it worth reconstructing

Sometimes it is better judgment to amputate a finger to save the hand, rather than to treat it conservatively for long and end up not only with the stiff finger but also with a wrecked hand from general stiffening of all of the joints. In that the ring of all the fingers if stiff, holds back the others from extending and flexing this principle

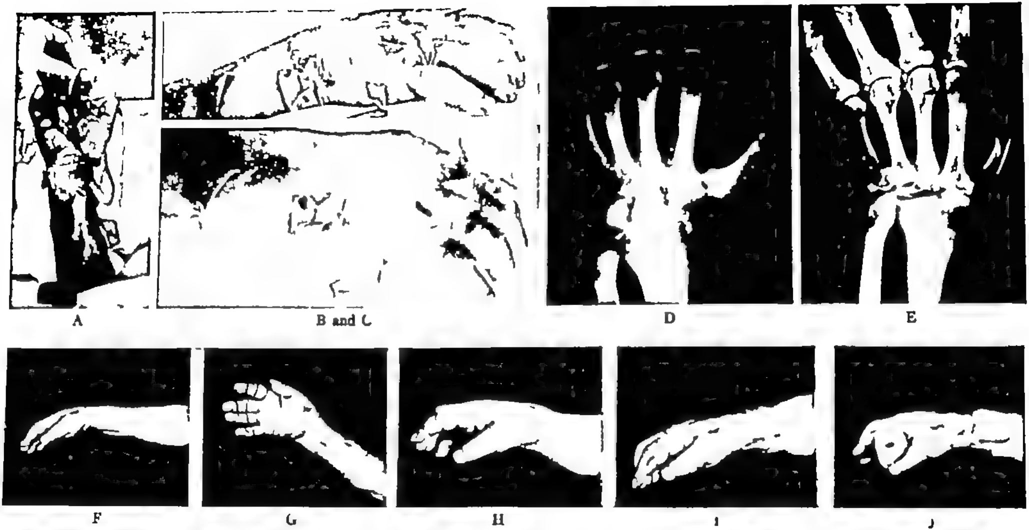

FIG. 622 Case G A. Severe infection of hand. From puncture of tendon sheath in pulp of thumb infection traveled up sheath down little finger through radial and ulnar bursae, midpalmar and thenar spaces, quadrilateral space in forearm and wrist joint. Healed seven months later

(A, B and C) Showing appearance during infection. (Courtesy I E. Harris.)

(D) X ray appearance of infected wrist joint. Radio-ulnar joint is always involved

(E) Carpals have been removed.

(F and G) Five months from healing hand is useless, cyanotic, very poor in nutrition digits move only one-half inch at their tips position of non function cannot even pick up a handkerchief

(H, I and J) Three months later hand has been improved a little by forcing joints around, suppling tendons, and excising head of ulna for supination so he can pick up objects from small to three inches in diameter The hand however is considerably disabled It will improve

should be considered in deciding to amputate it.

Infection in a joint, when at an early stage, may be stopped by *repeated aspirations and instillations of penicillin* (2000 to 5000 units per cc.). Parenteral penicillin does not penetrate into a joint sufficiently. Advanced joint infection treated by frequent aspiration and instillation of penicillin may subside but from damage to the cartilage *motion will be limited.*

WRIST JOINT. In a prolonged severe hand infection in which there is fusiform swelling in the region of the wrist and mostly on the radial side and in which there has been infection of the radial and ulnar bursae which constitute the usual cause, wrist joint infection should be suspected. There is moderate fever and not great pain because the infection is usually old. Tenderness extends about the circumference of the joint, and by shoving up through the joint or moving or straining it pain is produced. *The hollow between the extensors of the wrist and fingers is filled up, and aspiration here yields pus.* The head of the ulna shows to-and-fro extra mobility, swelling, and tenderness. Crepitus may be felt, and by x-ray is seen the loss of cartilage and disintegration of the carpal bones.

Anatomically, the radiocarpal, intercarpal, and carpometacarpal joints communicate, but the pisiform triquetrum, greater multangulum metacarpal, and radio-ulnar joints are separate. Clinically, however, the radio-ulnar joint is always also involved in wrist joint infection, resulting later in interference with pronation and supination.

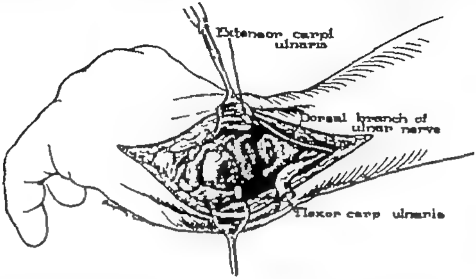

FIG. 623. Drainage for infected wrist joint.
Through a lateral incision the dorsal branch of the ulnar nerve is retracted dorsally and the insertions of the two carpus ulnari are severed. *Cutting of the capsule and abducting the wrist gives wide drainage.* The carpus ulnari reestablish their continuity

TREATMENT. Multiple incisions about the circumference of the joint do not drain well and have given very disappointing results in this formidable infection. Tendons may slough and carpal bones (often the lunate) may sequestrate. There is usually pointing in the ulnar side of the wrist and at other spots, and infection lingers long in the radial and ulnar joints. To obtain drainage, the proximal or both rows of carpal bones are removed. Bony or fibrous ankylosis may result.

In my later cases better results were obtained by combining the use of penicillin and sulfonamides with wide opening of the wrist from the ulnar side. Through a lateral incision over the joint, the tendons of the flexor and extensor carpi ulnaris are sev

ered at their insertions, and on cutting the joint capsule the wrist joint can be widely opened Necrotic carpal bones can readily be removed if necessary The head of the ulna should be removed to free the joint for pronation and supination Later, on closing the wrist joint together, the ulnaris muscles reattach well. Firm plaster splinting including the upper arm, to stop pronation and supination, should immobilize in supination and dorsiflexion until the infection is over, and then the wrist should be kept in position of function by a cockup splint, removing it often for exercising. Penicillin in addition to surgery is a tremendous help in treating wrist infections

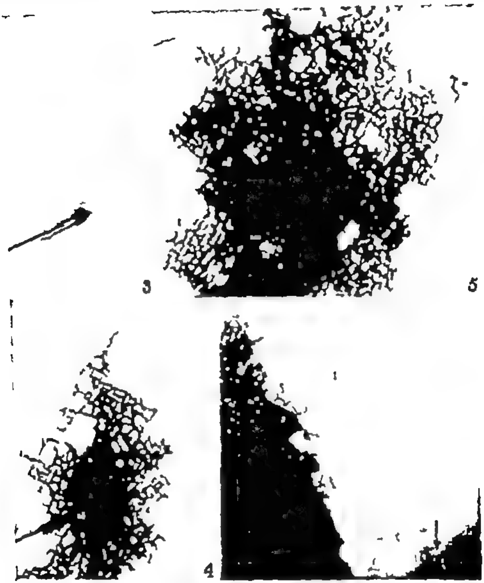

FIG 624 Showing the free lymphatic flow in the skin immediately after injection with India ink (3) Explains how diffusely spread is any lymphatic infection. (Courtesy Hudach, S. S and P D McMaster Jour Exper Med., 57 774 1933)

Infection in Lymphatics. LYMPHANGITIS Lymphangitis starts from a trivial superficial injury, and when under way spreads like a fire in a prairie. Throughout our surface tissue is a fine mesh network of lymph vessels that leads centrally in multiple trunks. The lymph glands—epitrochlear, axillary, and subclavicular—are the first filters for the lymph vessels from the hand.

All of us receive thousands of trivial superficial wounds in this layer of lymph

vessels, but only when infected by a viru lent Streptococcus or occasionally Staphylococcus which has become acclimated to a human host do we develop lymphangitis Even so, with prompt treatment the infec tion usually subsides but now and then—often in doctors and nurses who handle bad cases—an intensely virulent Streptococcus gets a start in our open, wide-spreading lymphatic system resulting in acute, rapidly spreading infection which in spite of all our modern treatment may be fatal. Fever and toxemia are intense, for nowhere, except in purulent thrombophlebitis, could there be a more perfect open system for rapid absorption It is the trivial superficial wound that places the germ exactly in this great superficial absorption system

Lymphatic System in Arms. Throughout the skin is a fine, squarish, meshed net work that when injected with a dye can be seen with the naked eye (see Fig 624) The network lies in the papillary layer of the

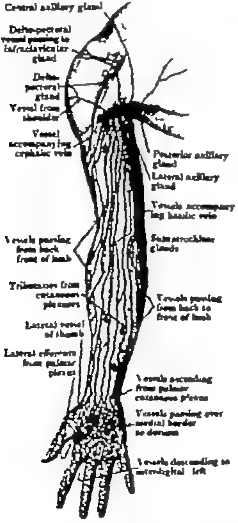

Fig. 625

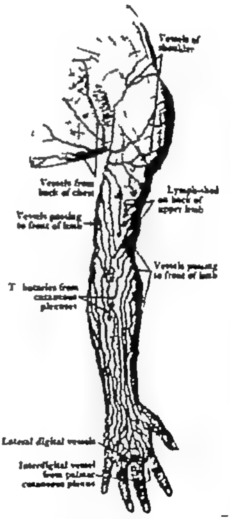

Fig. 626

Fig. 625 Superficial lymph vessels of front of upper limb *The fingers on the ulnar side drain to the epitrochlear glands and on the radial to the axillary*

Fig 626 Superficial lymph vessels of back of upper limb Drainage from little and ring fingers goes to the epitrochlear glands and from the fingers on the radial side to the axillary glands. Lymphatic vessels just below the elbow like the veins swing to the front around their respective sides. A small percentage from the long finger swing to the front in the upper arm along the cephalic vein to reach the subclavian gland (Courtesy Cunningham Textbook of Anatomy Oxford University Press.)

corium Blind ends from it extend into the papillae, and there is a deeper papillary plexus in the lower layer of the corium Hudach and McMasters found that when this network is injected by a fine needle with a dye its spread is rapid In four minutes the area of the dye in the lymphatics was 3 cm. in diameter In five minutes the dye extended 15 cm, and in ten minutes it had reached from forearm to axilla The larger lymphatics deeper in the fat, when dye-filled were visible to the naked eye

There is an especially dense meshwork of lymphatics in the skin of the palm, the volar and lateral aspects of the digits, and over the dorsum of the finger joints. The collecting trunks from these, two to four along the sides of the digits and many around the borders of the hand, converge to about 16 trunks that run up the dorsum of the hand and wrist. The trunks extend up the forearm in two main groups. Those from the thumb and radial border of the hand follow the radial border of the forearm and continue along the basilic vein to the lateral group of axillary glands, while a few from the long finger tend to follow up the cephalic vein to the deltopectoral and subclavicular glands. Those from the little finger and ulnar border of the hand follow up the basilic vein. Some from the extreme ulnar border enter the epitrochlear gland and from there continue as deep lymphatics to the axilla, but most skip the epitrochlear gland and continue along the basilic vein to the lateral group of axillary glands. Thus from the hand, the lymphatics in the main first converge and ascend on the dorsum and then diverge on their respective sides as they ascend the forearm, again to converge on the flexor aspect above the elbow The *different* trunks are quite variable and anastomose freely A few lymphatic vessels travel deeply along the three arteries in the forearm and converge to follow up along the brachial artery to the axillary glands.

Infection Of Lymphangitis is seen more frequently in the wintertime when vitality is low Point of entrance may be indefinite or it may be in a scratch, blister, or under a crust or other definite focus Acute lymphatic infection may flare up in an old wound as if newly infected Lymphangitis commencing in the palm may later become complicated by involvement of tendon sheaths, bones, joints, or fascial spaces, and so be worse than lymphangitis starting in the dorsum of the hand The latter may progress more rapidly, however, as its course is more direct.

Typically, lymphangitis has a rapid onset, with infection spreading soon up the arm to above the elbow There is then for a few days a hesitation in the progress, as if the body forces are balancing the invading infection Then comes a stage in which certain parts break down in abscess formation. This may be in the sheaths, fascial spaces, bones, or joints, or may be in a lymph gland—cubital, axillary, or subclavicular Subcutaneous abscesses may form at locations of lacunae in the lymph vessels, as on the dorsum of the hand, wrist, or flexor surface of the forearm When lymphangitis has been intense the infection spreads from the lymph vessels out into the surrounding tissue There is dense induration, and in this second stage the tissues liquefy and break down to diffuse, progressive cellulitis In these areas thrombosis occurs in the veins, and thus often pyemia. In any case of severe lymphangitis and lymphadenitis every organ in the body will be affected, showing gross pathology There may be general septicemia, and if the patient survives there may be legacy of endo-, peri, or myocarditis. In most bad cases hemolytic Streptococcus is found.

Symptoms The onset is usually sudden and severe, with pain and tenderness at the focal point and a chill soon followed by fever mounting to 102° F and up In 12 to 24 hours red lines are seen streaking up the arm, which are tender The hand be-

comes enlarged with soft, edematous, red, tender swelling, greatest on the dorsum but the fingers move painlessly and there are no signs of sheath-or fascial-space infection. The lymph glands involved are painful, tender, and swollen General toxic symptoms are great for the appearance of the lesion restlessness, headache, malaise, sweating, loss of appetite, and vomiting The patient looks sick and feverish and the pulse is bounding

The course may be so terrific that in spite of treatment death may occur in 24 to 48 hours Nine out of ten cases, however, quickly respond to treatment and are promptly well again Temperature may reach 102 and 103° F in the first three days, but under prompt compress treatment in a hospital these mild cases clear in two to ten days without any complications Between these two extremes are all grades of severity In some which do not subside so promptly there follows, after the initial onset, an abscess in the gland or at the lacunae in the course of the lymphatics, on the dorsum of the hand, wrist, or forearm, or in the flexor aspect of the wrist.

Cases which are more severe run a more stormy course for a week or ten days, in which the whole arm swells and shows redness and blebs. Then, after a pause, come the various complications mentioned above. Tenosynovitis may run its course extending to bones, joints, and spaces, or the whole surface of the arm may break down in phlegmonous cellulitis. Thrombi from the clotted veins or even free pus in the veins may disseminate the infection to the lungs or throughout the body, causing multiple lung abscesses or pyemia. Such severe cases may need amputation and if they do not die have a long, stormy convalescence. Involvement of the deep lymphatics is suspected when the whole arm is greatly swollen and signs of abscess formation appear along the course of the arteries, such as in the quadrilateral space in the forearm. The worst type of acute spreading infection may pass rapidly to septicemia, the temperature is 105° F, the toxicity is overwhelming There may be diffuse cellulitis or phlegmon of large areas of the arm. A third die in a few days to a week or two and many of the remainder develop complications.

A more detailed description of lymphangitis may be found in the excellent article by Koch.

Treatment In lymphangitis there is often no apparent focus of infection, the infecting organism having spread so rapidly through the lymphatic system that the original focus has lost its identity In such a case, incision for drainage is not only useless but decidedly harmful, in opening up new lymphatics and spreading virulent infection. Surgical incision has been ardently warned against by Kanavel and Koch, who claim that most bad cases have had ill advised incisions Undoubtedly the best rule to follow is avoidance of these incisions. There are, however, cases which show a very definite focus, such as a drop of pus under a crust or blister or a pustule where lifting a lid or very locally liberating the pus will eliminate the focus Only such a focus should be attended to but without cutting through an area of tissue. Every patient with lymphangitis should be placed in bed in a hospital and the hand and arm elevated and wrapped in a voluminous warm compress reaching to the axilla. Outside the cellophane of the compress should be some hot water bags heated to 110°, with a blanket around this to hold in the heat. Sulfonamides and penicillin should be pushed. Water is forced until the daily urine is 1000 cc. and proteids are maintained by transfusions of blood The appropriate serum based if possible on direct culture of the particular organism, should not be omitted in severe cases Even when abscess commences to form one should err on the side of delaying surgical drainage rather than rush in too quickly and disseminate infection. Tenosynovitis joint and bone infections, abscesses and cellulitis

demand drainage. Where possible, one arm of the L-shaped incision for cellulitis, if placed transversely just proximal to the abscess, will tend to block the upward passage of the infection In very severe cases, life saving amputation must be considered

Treatment of Infections

General Procedure

Treatment must be preceded by exact diagnosis of the type of infection—fascial space, tenosynovitis, or lymphangitis—and of the exact boundaries of the infected areas. When pus is under tension the bacteria are forced into the tissues, but with drainage they flow out. If fascial space infection it should be drained, but this is not urgent. Tenosynovitis should be drained at once, but in lymphangitis one should refrain from accelerating and spreading the infection by incising

We should be on guard lest an underlying general disease be present, such as diabetes or blood disease, or a vitamin-C or D deficiency

If it is a case of fascial space infection, tenosynovitis, or lymphangitis, hospitalization is indicated and all but trivial cases and those of lymphangitis should be opened under general anesthesia and the ischemia of a tourniquet. Local anesthetic spreads infection and should not be used unless injected only in the line of the incision. Block anesthesia is dangerous in acute infection, as it plows the soil for quick metastatic infection to the region injected Ethyl chloride gives real anesthesia for a minute or so only if used in conjunction with a tourniquet. With it one can operate on a paronychia or other small infection

Of quick useful general anesthetics there are sodium evipal and pentothal and also nitrous oxide-oxygen and cyclopropane.

In using a tourniquet the blood should not be first wound out of the limb with an Esmarch bandage because this would express the infection into the circulation Instead, after placing a blood pressure cuff loosely on the arm, the latter should be held vertical to empty it of blood Then, with one stroke of a bicycle pump, the blood pressure band is filled so as to reach

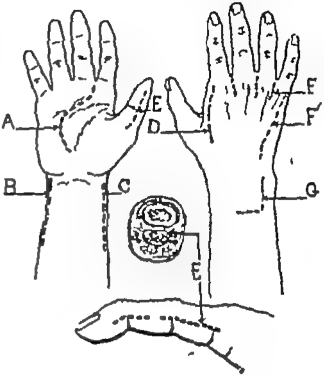

FIG. 627 Incisions for drainage.
(A) For midpalmar space
(B) For ulnar bursa
(C) For radial bursa
(D) For thenar space
(E) For tenosynovitis always midlateral behind the nerve and vessels. In front of the latter leads to keloid contracture. The flexion creases end at the midlateral line, as to-and fro stress stops here
(F and D) For subaponeurotic space
(G) For subcutaneous abscess. Cross arm of incision blocks extension

the pressure of 300 mm of mercury before the heart beats fill the arm with blood, as they will if the rubber bulb is used. Under ischemia one can see to open correct spaces or sheaths where the pus is and not inoculate the wrong ones, and can follow the pus in all its extensions

Drainage

The area should be shaved and well cleaned with soap and water, all crusts and scales being removed, leaving only clea skin. Before expressing the pus from

Fig. 628 Position of nonfunction from neglect following infection of wrist joint from buzz saw injury and removal of carpals. Limits of flexion and extension are shown.

sinus or incision for drainage, one should carefully press around, starting at the outskirts, to determine the exact area of the abscess over which pressure will cause pus to escape The incision should be chosen *with thought so as to drain widely, often* through an L-shape or flap, and so as to block by its cross arm the upward extension of infection. It should afford dependent drainage and not make a flexion contracture by crossing a flexion crease at a right angle. If an annular ligament must be severed, it should be done laterally, not through its center Regard should be had for small nerves, for not unnecessarily exposing tendons or cutting off blood supply Drainage should never be through and through either in digit or in hand Types of incisions may be found in Fig 627 The dorsum of the hand may be swollen, but it rarely need be incised Devitalized or necrotic tissue should be excised lest it nourish the germs and prolong infection Through out the wound are placed slender catheters with fine mesh gauze folded about them. They should not contact either tendon or joint cavity The catheters are led out of the dressing and there kept sterile Penicillin (250 U per cc.) is injected in each catheter every three hours at the same time as the parenteral dose. All is kept in place for at least four days, at which time it will be loose, the wound will be red, and a barrier will be established against infection. Moreover, the wound will then not have been harrowed up and reinfected by early daily dressings. After that, usually drains are no longer necessary

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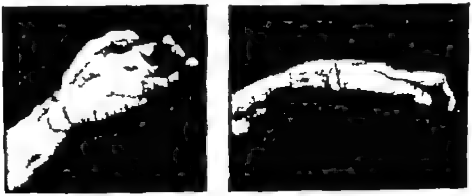

Fig 629 Case O J Hand wrecked by infection. Starting from puncture in thumb pulp into tendon sheath it traversed the tendon sheaths and fascial spaces including the arm causing severe illness. The little finger became gangrenous. Drainage was inadequate lasting 5½ months, and position of function was not maintained.

Subsequent Care

From the beginning, the hand is kept on a metal cockup splint to keep the part at rest and to hold the wrist dorsiflexed, proximal joints flexed, the thumb in opposition, and the arches curved The piece fitting into the arch of the hand and curve of the thumb can be swiveled on its rivet to fit either hand

The hand should be given rest, elevation, heat, moisture, and be kept clean Parts of the hand not infected should be free to move Elevation, by keeping down the edema, improves circulation and lessens subsequent adhesions Heat can be maintained by a hot water bag or a 25 watt electric light in a cradle placed over the hand. Heat should never be over 110° F, as sick tissue cannot tolerate excessive heat, lukewarm is a good expression. Moisture is added with each change of dressings, or the dressings may be changed only daily and the liquid squirted in every few hours by a nurse. Wounds do much better if kept clean Neglected wounds, dirty and with necrotic areas and with the surrounding skin covered with hair, crust, and piled up soggy epithelium, improve miraculously if merely cleaned up The culture media—old epithelium and débris—should be removed from the skin with a spoon curet until down to the living epithelium which can protect itself Colebrook has shown that bacteria penetrate a wet compress to the wound in a few hours, but not if it is enclosed in cellophane

Septic wounds should not be traumatized or made to bleed and should be dressed with aseptic precautions to prevent adding a new infection. Baths are of doubtful value for this reason. Alternating with compresses, the wound and the hand do well if they are allowed to dry in the sun or electric light, to prevent sogginess. Later, healing is hastened by half hour exposure to ultraviolet rays, preferably from sun light Infected wounds do poorly with ice but improve with heat If hot compresses are too long-continued granulations will become luxuriant and heal with excess of scar Three useful solutions for compresses are

8 per cent sulfanilamide or penicillin 250 u per cc
Boric solution with ¼ per cent sodium citrate.
Normal salt or Ringer s solution

The citrate keeps wounds draining by preventing lymph from clotting The Ringer s solution inhibits healing the least.

The above system of treatment might be called the cleanliness method It is reliable and rapid in results Excellent results are also obtained by the septic tank or Orr method, in which the wound is well opened, packed with petrolatum gauze, and encased in plaster to work out its own sterilization Though excellent elsewhere and in osteomyelitis of one bone in a hand, my experience with it in extensive hand infection has not been good because of the tendency for the infection to extend to the various compartments within the hand A compromise method of packing a wound lightly with fine mesh gauze or rayon instead of petrolatum gauze, using penicillin locally and penicillin and sulfonamides parenterally, and of dressing and cleaning up the wound infrequently, such as once a week, has much in its favor in preventing the reinfection from daily dressings and in allowing natural favorable processes to work in the wound. This makes for great saving of expense of material and nurses over the compress treatment. A dressing should be done on any rise in temperature

Antiseptics

Little has been said of the use of antiseptics the trend is away from them, but not entirely They act promptly on the infection, but when persisted in so damage the tissues that the wound is gray and healing prolonged They are useful in keeping foul, pus-filled dressings sweet and in rid-

FIG. 628 Position of nonfunction from neglect following infection of wrist joint from buzz saw injury and removal of carpals. Limits of flexion and extension are shown.

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found, but there may, also, be *Cl sporogenes*, *Cl tertium* or *Cl histolyticum* With these may be Staphylococcus, Proteus, *Esch coli*, *B pyocyanea*, and nonhemolytic Streptococcus, some of which destroy penicillin by producing penicillinace necessitating an excessive amount of penicillin or else some antiseptic. Treatment should be immediate and radical The wound should be excised widely, removing all necrotic tissue with the bulk of invading and resisting organisms and packing the wound open Sulfadiazine and penicillin have real value and should be given in full doses, the latter, also locally Penicillin is effective in lowering mortality in gas gangrene after adequate excision of devitalized tissue, but is relatively ineffective without such supportive surgical excision (Lyons) Antigas bacillus serum should be given in accordance with the direction on the individual package X ray treatment is of doubtful value When gas gangrene is present, if a muscle group is involved the length of that group should be excised and if several groups amputation is indicated The wound may be filled with creamy suspension in water or normal salt solution of medicinal grade of zinc peroxide Over this is placed wet gauze and all is covered with an impervious dressing of petrolatum gauze or cellophane to prevent evaporation Every day or two the wound should be washed with normal salt solution and similarly redressed Transfusions of whole blood are repeated as needed Mortality from established and well treated gas bacillus infection is still in the neighborhood of 25 per cent

General Treatment in Infections

Infection is increased by fatigue, chilling, dehydration anemia (hemorrhage), starvation (low proteid), and deficiency in vitamins (especially C, A, and B) These are all deficiencies—namely, of vitality, heat, water, blood, proteid, and vitamins—and all can readily be supplied. If there is not a deficiency in any or all of them it will be of no benefit to supply an additional amount. This applies particularly to the vitamins both locally and generally Too much vitamin A and D locally has even hindered healing

The first two are supplied by rest in a warm bed The water intake should be from 3,000 to 4,000 cc daily or until there is a 1,000- or 1,500-cc. output of urine. With enough water the urine should promptly clear of casts and albumin

Blood and proteid are supplied by food and transfusion of plasma or blood A positive nitrogen balance is established by transfusions of blood and also a high caloric diet of 2,500 to 3,000 calories rich in proteids up to 150 grams a day When blood proteid is low healing is poor, wounds rupture easily, and the tissues become edematous and weep Hemoglobin percentage should be kept above 80 and blood proteid up to 7 Gm per 100 cc., supplying plasma or whole blood whenever necessary

When vitamin C is deficient healing of wounds is poor and with insufficient collagen, the material that binds Wounds rupture with only a third the normal strain they should resist. Infection is increased, as in scurvy C content in the blood is poor in infections as more is used and the output is less. Vitamin C is essential in the treatment of infections in the presence of deficiency

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When vitamin B is deficient regeneration of red corpuscles is poor In severe infection sufficient vitamins should be supplied by haliver oil, brewer s yeast, and citrus fruits or the equivalent in vitamin barrage

Cross-contamination of wounds or adding *mixed infection* should be scrupulously avoided. Those handling wounds should not contaminate their own hands, and should be masked during dressings to avoid infection from nose and mouth spray

ding of bacteria splints and surrounding surfaces other than those of the wound but they cannot reach the germs deep in tissue without killing both.

Necrotic tissue may be sterilized by touching it with antiseptic, such as silver nitrate, tincture of iodine, and gentian violet The latter, 1 to 5 per cent strength with cleanliness and 1 or 2 per cent acetic acid is useful in combating *Bacillus pyocyaneus* An infection which is so severe that it overpowers the resistance of the patient can sometimes be checked by the brief use of an antiseptic, until physiologic methods come to the rescue.

Acriflavine in from 1 1000 solution in water or glycerine is useful on occasion. Sodium hypochlorite or Dakin s solution under the trade name of Hychlorite dilute with seven parts distilled water, yields a solution with pH between 4.5 and 5 0 which lasts seven to ten days and is used in compresses or by the Dakin irrigation method. It quickly clears severe infection and dissolves slough. A stable form of chlorine is azochloramide in triacetin 1 500 —or in normal salt solution 1 3300

Other Aspects

If a finger is too badly damaged ever to be reconstructed the infection may be quickly terminated by amputation. If infection is prolonged in one finger in an elderly person and is stiffening up the whole hand, amputation may be indicated—especially if it be the ring finger, for this finger especially if stiff, prevents the adjoining fingers from flexing

Joints should be maintained in position of function by a simple volar metal splint and as soon as the acuteness of the infection is over motion in them should be started and persisted in This will work out the edema and prevent stiffening of joints and adhesion to tendons An infected hand should be kept well elevated to lessen edema which hampers circulation and is the arch stiffener of hands While the hand is incapacitated the arm should frequently be raised to the vertical at the shoulder, or eventually the patient will not be able to raise the arm If an infection lasts too long one suspects infection of a bone, joint, or tendon, and if the fever and symptoms seem too great infection of a joint is suspected. In the course of infection, one or repeated severe hemorrhages may come from the superficial or deep arch in the hand or the ulnar artery in the quadrilateral space in the forearm. Such a hemorrhage comes from a lateral hole eroded into the vessel which cannot be plugged by a terminal clot The artery should be exposed at once, cut across and each end ligated.

Phagedenic Infection

In severe phagedenic anaerobic infection after excising the necrotic tissue as advised by Meleney, the wound is packed with a 25 per cent suspension of zinc peroxide All is then covered over by an impervious dressing as described under gas-bacillus infection. The treatment should be radical just as with gas gangrene

Gas-bacillus Infection

Like the Clostridium of tetanus a necrotic, infected field or one with a foreign body is essential for the growth of the anaerobes of gas infection, instead of a field of clean, vital tissues Such infection, therefore, occurs in crushing or gunshot wounds and is more readily prevented than cured. Early complete surgical débridement or excision of the wound is the greatest preventive Next in importance but without surgical excision helpless, are penicillin and polyvalent antigas bacillus serum. Gas bacillus infection is identified by the odor, the brick red or later bronzed appearance of the muscle, the gas in the tissue (sometimes seen by x ray) pain, rapid pulse and the clostridia demonstrated in smears The various bacteria should be identified specifically *Cl welchii* is the usual one

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Chemotherapy

Sulfonamides Since Domagk in 1935 proved that mice could be protected from a fatal dose of Streptococcus by prontosil, sulfonamides have rapidly become the established treatment for infections, greatly changing our former conception. Their use will greatly aid surgery of infections, but will not supplant it nor allow us to let down in our main surgical principles. Surgery will, however, be modified toward less radicalism in incisions and drainage. Not yet can we, with sulfonamides alone, always stop acute spreading infection or without surgery cure acute tenosynovitis The sulfonamides have a definite effect in checking most of the germs of wound infections including gas-forming Clostridium They are very valuable though their potency is far less than that of penicillin These two drugs may be given together

Sulfanilamide, sulfathiazole and sulfadiazine are the drugs of choice the latter two affecting Staphylococcus and gas bacillus in addition to Streptococcus. Enough sulfanilamide is given to raise and maintain the blood to the following requirements, depending on the severity of the infection

Severe Cases and Those with Bacteremia.	10 to 15 mg. per 100 cc. blood
First 24 hours	1 to 1½ gr per pound or 150 gr for average adult, for children, 1 gr per pound
Initial dose	50 to 75 gr and then 15 gr four hourly
Subsequent days	15 gr four hourly
Average Severity	5 to 10 mg. per 100 cc. blood
First 24 hours	Initial dose 45 to 60 gr and then 15 gr four hourly
Subsequent days	15 gr six hourly
Lesser Severity	3 to 5 mg. per 100 cc. blood
First 24 hours	Initial dose 30 to 45 gr and then 10 gr four to six hourly

Dosage. The amount of sulfathiazole and sulfadiazine is half as much again in the initial dose. In from 24 to 48 hours all will have been excreted.

Complications Complications occur in some, and should be guarded against by frequent blood counts and urinalyses to detect leukopenia and kidney involvement Including presence of sulfonamide concretions If the daily urine output drops below 1,500 cc. the dose should be decreased, stopped if it diminishes still farther, fluids forced, and alkalization carried out to prevent fatal anuria from blockage of kidneys or ureters by accumulated sulfonamide crystals. Other complications are nausea, vomiting, disorientation skin eruption cyanosis, and fever In some there seems to be an action on cells similar to bacteriostasis in that the skin becomes eroded and the granulations red and unhealthy

Local Use. It was hoped that the sulfonamides would replace our former antiseptic solutions, ointments oils emulsions, and ingredients of prepared gauze Our hopes for local application have diminished and our main reliance is placed on their use systemically In parallel series in 1500 cases under the direction of Meleney the local frosting of various kinds of wounds with sulfonamides did not diminish the incidence of infection though it did limit the spreading and lessened the virulence Sprinkled to excess it acts as a foreign body In vitro sulfonamides inhibit proliferation, but do not kill bacteria or lessen virulence In wounds blood pus or necrotic tissue, if present, destroy their effect on bacteria, but locally on skin or a clean surface the sulfonamides are effective. Used locally on extensive surface such as burns they may result in absorption to toxic degree Occasionally a sulfonamide by exercising its bacteriostatic effect on epithelium causes denudation Locally sulfanilamide has been used as a diluent for applying the calcium salt of penicillin by insufflation. This is

very effective, but the action is due to the penicillin.

Penicillin Just now this potent agent against infection has come into use In 1929, Fleming noticed that when the mold *Penicillium notatum* grew on an agar plate with colonies of Staphylococcus the latter melted away as if the mold for its own protection had the power of lysis over other intruders. Eleven years later Chain and Florey learned how to grow the mold, extract the penicillin and, with others, found a similar action on Streptococcus and the clostridia of gas gangrene. In 1941, Abraham and the Oxford investigators applied the principle in treating human infections It was tried out by the military in 1944 and became available to the public in 1945

THE DRUG. This extract from the mold, concentrated a thousand times and produced as crystals by Hobby, Meyer and Chaffee in 1942, is highly soluble in water but easily destroyed by alteration in the pH In the blood stream or locally it is powerfully bacteriostatic, and is quite safe as its toxic dose is nearly 64 times its effective dose. Leukocytic action so essential in chemotherapy is not hampered up to a concentration of 1 500 The bacteriostatic action is not interfered with by the presence of pus, necrotic tissue or abundance of bacteria. The drug however, must reach the bacteria to be effective. Fortunately it is not toxic, the worst effects from it being urticaria in two to five per cent usually in the second week, occasional vesicular eruptions slight local pain, occasional thrombophlebitis at injection and occasional cramps and diarrhea, none of which demand discontinuance

When dry the sodium salt of penicillin keeps for a year at 10° C, but deteriorates rapidly in solution at room temperature The crystalline sodium salt keeps at room temperature. Solutions should be kept in a refrigerator and should be made up fresh each day Anhydrous salves will keep at room temperature for a period of one or two weeks and at 10° C one or two months

METHODS OF ADMINISTRATION Due to the rapidity of elimination, mostly through the kidneys, the blood concentration must be kept up by constant administration, such as by continuous intravenous drip, three hourly intravenous injections by syringe, or preferably intramuscularly, as by this the blood level is better sustained It should range according to the susceptibility of the germ from 015 to 15 U per cc.

Penicillin is available in ampules of 100,000 Oxford units as the sodium salt, which is a very soluble brown powder It is administered in isotonic saline or glucose solution An Oxford unit is the amount of drug added to 50 cc. broth that will stop the growth of *Staphylococcus aureus* Locally, the powder being irritating, a solution of 250 to 500 units per cubic centimeter is used and is effective It may be instilled to the depths of the wound by a tube system Irrigations are useless as a contact of six to eight hours is necessary to be effective. Antiseptics should be omitted as they destroy penicillin The calcium salt diluted to 1000 to 5000 units per gram with sulfanilamide, which serves as an inoffensive powder, has, by the British, been applied to wounds by insufflation with excellent results It was found that much of the irritation was from impurities (Florey), and that the sodium salt acted as well. Somewhat better results, however, in secondary wound closure were obtained by parenteral penicillin Florey and Williams ran a parallel series of 212 various hand infections, half being treated in the usual way and the other half by placing daily in the drainage wounds the powder of the calcium salt of penicillin It was omitted parenterally They found in the latter cases that in general, sepsis was eliminated in a week Pain and throbbing were relieved. Healing time was reduced and there was a rapid return of movement There was a mild complaint of burning

For intravenous drip 25 to 50 units per cubic centimeter is used. By the end of the

first hour, half of the dose will have been excreted by the urine so the intramuscular method by which the blood titer is prolonged to three or four hours is preferable

The routine administration was parenteral, the prevalent method being to give intramuscularly at intervals of three or four hours 5,000 Oxford units per cubic centimeter by syringe, giving 15,000 to 50,000 at a time and supplemented each time by a local application

Intramuscularly 100,000 units eliminates the gonococcus, the most susceptible germ, in 90 per cent of cases in 24 hours Streptococcus hemolyticus yields under 100,000 units daily *Streptococcus nonhemolyticus* and *viridans* require larger doses for longer times, and Staphylococcus two or four times as much, such as 240 000 units daily for two or three weeks Resistant cases need as much as 400 000 units daily For constant drip intramuscularly 120,000 units in 250 cc. normal salt solution is used. In bacteriemia the germs are accessible and so are more easily eliminated than where there is a nidus of infection from necrotic tissue In bacteriemia of Staphylococcus 300,000 units daily are needed Penicillin prevents mitosis and the secretion of toxins, leaving to the body forces the elimination of the germs Parenteral penicillin does not reach necrotic foci, abscesses or sequestra. For these surgery is all important To surgery penicillin is only a helper

Penicillin in oil and wax is available in syringe units for intramuscular use, each containing enough dosage for 24 hours. Administering the dose but once daily is practical for convenience though the percentage in the blood may vary somewhat between doses

Crystalline penicillin G with procaine in aqueous suspension is now in prevalent use It is not as objectionable as the oil and wax preparations A single dose of 300 000 U intramuscularly maintains sufficient blood level for 24 hours

Ointments of 250 to 800 units per gram in an anhydrous base are used on skin and wounds. Penicillin by mouth is ruined by gastric juice so double gelatin capsules treated by formalin and alcohol are used Five times the intramuscular dose is needed to keep up the blood titer for 24 hours so at this stage of our progress this method is effective only on very susceptible germs.

The following are two lists showing which germs are susceptible to penicillin and which are not.

Penicillin susceptible	Not penicillin susceptible
Most gram positive bacteria	Gram negative bacilli
Gram negative Diplococci	Esch. coli
Streptococci	B typhosus
Staphylococci	B dysenteriae
Cl welchii	Enterococcus
Cl. perfrengens	Streptococcus faecalis
Cl. botulinum	Proteus
Cl. oedematiens	T pyocyanea
Cl. tetani	H. influenzae
Cl. histolyticum	H. pertusis
Gonococcus	P pestis
Meningococcus	B friedlander
Pneumococcus	Brucella
C. diphtherae	M. tuberculosis
B anthracis	P tularensis
T pertenue	Monilia
Borrelia novyi	Vibrio cholerae
Actinomyces bovis	Coccidioimycis
Treponema pallidum	Yeasts
B subtilis	Molds
	Leishmann Donovan bodies
	Blastomycoses

Penicillin should be used, both for cure and prophylaxis, in all cases infected or potentially so, such as fresh injuries, burns, any long reconstruction operation where infection would wreck the result, where latent infection is possible, secondary closures of wounds, successive operations on osteomyelitis, acute haemolytic osteomyelitis, gas gangrene, tetanus, anthrax, actinomycosis, gonococcal infections lues and diphtheria infections of hands. Infections within joints or tendon sheaths like those within the pleural membranes or in the spinal fluid *being beyond the penetration of* penicillin parenterally need treatment by direct instillation For this 1000 to 5000 U per cc. is needed.

With penicillin we are better able to close wounds per primam and are even able to apply pedicle skin grafts immediately after the injury which was formerly a dangerous procedure. Secondary closures of wounds are safer, and now with it we can operate on osteomyelitis or densely infected scar tissue in weeks instead of months. Penicillin has opened up new possibilities in surgery, but it is far from being a cure-all. Proper surgery cannot be disregarded. It is still needed to liberate pus and to convert the linings of our wounds to bleeding tissue by removing dense scar, sequestra or products of necrosis. Failures are from using too little penicillin, stopping too soon, necrotic tissue, foreign body or sequestra preventing contact, and from using deteriorated drug.

Some bacteria are penicillin resistant including some strains of Streptococcus and Staphylococcus and common contaminants such as *B. coli*, Proteus and *B. pyocyaneus*. An identifying culture should be made from each wound as a guide in treatment. The degree of susceptibility or resistance is easily determined in the laboratory. Resistance demands a larger dose. Certain bacteria produce an enzyme called penicillinace (Abraham and Chain 1940) which destroys penicillin. Of these there are aerobic nonspore-forming gram negative bacilli, *Esch. coli*, Proteus, *B. pyocyaneus*, *B. subtilis* and some gram positive spore-bearing bacilli. Resistant strains seem to be the natural residual in wounds after penicillin treatment, though their resistance may have been acquired. Efforts to prevent penicillinace from destroying penicillin have been made by giving excessive doses of penicillin and destroying by an antiseptic these resistant bacteria. For this Meleney advised P. chloro phenol as effective.

Penicillin is effective in generalized infection and in preventing spread. Its limitations, however, are definite. Surgery is necessary to relieve tension from pus and remove sequestra and necrotic tissue. Any hand infection with pus should be drained.

Tyrothricin. In 1939 Dubos found a natural antibacterial substance elaborated by the anaerobic spore-bearing soil bacterium, *Bacillus brevis*, effective against gram positive organisms. This substance known as tyrothricin contains gramicidin and tyrocidine. Almost as nontoxic as is penicillin, it is relatively insoluble in most solvents and is used only locally, as it is dangerous if it reaches the blood stream. It is used as a suspension in water in infected wounds and cavities, solutions deteriorating in seven to ten days. Compared with sulfonamides it is far more effective locally and it acts on many gram negative bacteria on which penicillin does not, though not on *T. pyocyanea*, *B. pseudomonas*, or diphtheroid bacilli.

Streptomycin. Streptomycin was isolated in January, 1944, by Schatz, Bugie and Waksman from a filtrate of a culture of *Streptomyces griseus*, a mold like dweller of the soil with the odor of freshly plowed earth. It is quite similar in action to tyrothricin, but is somewhat stronger in action on some germs and is less toxic. It is not as potent as penicillin. Unlike tyrothricin it is given intramuscularly and subcutaneously and intrathecally. Topically tissues tolerate 200 U per cc., and granulation tissue 1,000 U per cc. It is potent in pus and locally, when applied with, is supplementary to penicillin. Intravenously it should be given only with care to prevent collapse. It is not absorbed in intestines and is excreted in the urine.

Available as a dry powder of the hydrochloride or sulfate 1 Gm. to a vial, it is water soluble and keeps well dry, but solution should be made up daily and kept in a refrigerator. The 1 Gm. of powder in a rubber stoppered vial is diluted 1:10 or 1:20 with normal salt solution and administered intramuscularly in 0.5 Gm. dose twice daily. A little novocaine may be added to prevent pain. Intrathecally 50 to 500 mg. are dissolved in 5 to 10 cc. of solvent.

Streptomycin, though not as potent as

penicillin, is effective usually in 1 or 2 weeks, mostly on gram negative germs but to a lesser extent on some that are gram positive. It is more effective alkaline but this predisposes to renal calculi. Germs rapidly develop resistance, so the infection should be promptly controlled by using sufficient dosage. Some germs that are susceptible are *B. proteus, P. tularensis, H. influenzae, P. vulgaris, Aerebacter aerogenese,* and *E. coli*, some that are not susceptible are *B. typhosis, T. pyocyanes,* brucellosis, salmonella, clostridia, molds, fungi and viruses. A culture from a wound should be routinely tested for resistance or susceptibility to both penicillin and streptomycin, as the various strains of each germ differ especially in regard to the latter. It is bactericidal to human *M. tuberculosis* in vitro, but in vivo, where the germ is sealed in caseation, seems to only arrest the disease. It is especially valuable during and after operations on tubercular areas as it then reaches the bacteria exposed from the operation. Combined with sulfonamide, and in large doses, it is partially effective against pyocyaneus.

Mild toxic symptoms may occur, such as headache, weakness, disability, fever, rash, urticaria, arthrosis and myalgia. Sensitization may occur, but the patient may be desensitized. Troublesome toxic symptoms are involvement of the eighth nerve, vertigo, tinnitus and deafness. These usually come after two weeks of streptomycin and, though in most cases are mild and transient, they may be severe. If treatment is discontinued in eight days, or if the dose is as low as 1 Gm. daily, they are usually avoided. Most people tolerate streptomycin well for one or two weeks, and if it were not for the eighth nerve symptoms, for four months.

Aureomycin is a product of streptomycin aureofaciens, reported by Duggar in 1948. It is potent against cocci both gram-positive and gram negative and also the organisms of the usual urinary infections, typhus, Rocky Mountain fever, spotted fever and

FIG. 630. Tuberculous dactylitis of medullary origin. (Courtesy de Quervain, F. Clinical Surgical Diagnosis, p. 713. London: John Bale Sons & Curnow, 1932.)

Q fever. It is only mildly toxic, causing nausea, vomiting, loose stools and rashes. The dose is one gram, orally, every 6 hours.

BACITRACIN

Bacitracin is a product from a strain of *B. subtilis bacillus* named after Tracy and is effective against the following bacteria: Staphylococcus, pneumococcus, gonococcus, meningococcus, lostridia of gas and tetanus, and many other organisms. It is not destroyed by blood or pus and has been found to be effective in 88 per cent of the usual local infections. Being nephrotoxic, it is used only locally. 500 U per cc. in solution or ointment is used locally. It is available in rubber-stopper vials of 2,000, 10,000 and 50,000 units and is especially useful for patients who are sensitive to penicillin.

SPECIAL INFECTIONS OF HAND

Tuberculosis

Tuberculosis occurs in the hand in the skin, tendon sheaths, bones, and joints. Infection is direct or blood borne and the spread is by contiguity along tendon sheaths, fascia, lymphatics, and from bone to joint. The resistance, virulence, and secondary infection govern the picture and trauma accelerates it. Those who work

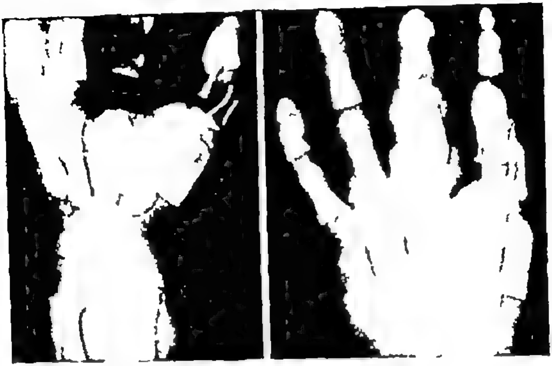

FIG. 631 Tuberculous dactylitis periosteal type. (*Left*) Of metacarpal. (*Right*) Of proximal phalanx.

with tuberculous cattle or tuberculous persons are prone to direct infection

Skin

From local inoculation there develops an indolent, red papule growing slowly from one fourth inch in diameter to one inch. This is called an anatomic tubercle and breaks down to a chronic, blue, undermined ulcer Other forms are verruca necrogenica, verrucosa cutis, and lupus vulgaris. The diagnosis is by clinical pictures, guinea pig inoculation, and biopsy

Treatment if early is by excision and skin graft if late by cauterization and curetting, with sun, quartz light general care

Bones and Joints

Tuberculosis of the bones of the hand, which is more common in children than in adults, is blood borne to the phalanges, metacarpals, and carpals, and secondarily involves the joints. One or many of these bones may be infected.

Phalanges and Metacarpals In the phalanges and metacarpals in children the infecting emboli, unlike their custom in other bones to lodge in the epiphyses, usually land in the medullary cavity of the shaft. Here, in a finger they set up a spindle dactylitis or spina ventosa

In these bones in adults the infection is more likely to be periosteal, starting in the epiphyseal line and extending to the periosteum or into the joint.

In the first or medullary type granulation tissue fills the cavity, causing patchy necrosis and absorption of the spongy portion with sequestration of the diaphysis An involucrum forms about the shaft and is gradually distended by the granulomatous mass within

In the periosteal type the thickening

FIG. 632 Tuberculous dactylitis, advanced and with sequestrum. (Courtesy Newell Robert Stanford University School of Medicine.)

periosteum gradually shuts off the blood supply to the whole shaft which dies, and when this is finally extruded the finger shortens because no involucrum has formed

Either type runs a chronic course leading to cold abscess, sinuses, long suppuration, secondary infection, and crippling of the finger The finger joints may also be infected, leading to ankylosis—especially in adults.

DIAGNOSIS. Tuberculous dactylitis is distinguished from the syphilitic form by less proliferation and a typical spindle-shaped distention. In the periosteal type there is no outside thickening of the periosteal surface of the bone which is so typical in syphilitic dactylitis Cysts and tumors may be ruled out by appearance, biopsy, and guinea pig inoculation

TREATMENT Tuberculous dactylitis should be operated upon before suppuration and penetration to the outside occur by opening the bone, curetting, removing the sequestrum, and closing without drainage followed by long splinting and heliotherapy in moderation If too late for closure, the sequestrum can be removed followed by long splinting and drainage. If complicated by joint infection the finger should be amputated. The prognosis is good in children, but in adults there may be long suppuration or the necessity of amputation

Wrist Joint. Tuberculous involvement, though infrequent, is more common in children—especially between the third and ninth years—and is rather rare after 20 In children it is secondary to carpal infection, but in adults is more commonly by contiguity from neglected tenosynovitis.

The wrist shows fusiform swelling is slightly flexed, and the forearm and hand muscles are atrophic. Some pain is present, and because of it motion is limited by muscle spasm. X ray shows some or all carpal bones with porosis, disintegration, or fusion Eventually pus works through and the mass is riddled with sinuses.

TREATMENT Immobilization in dorsi flexion should be started early Prognosis in children is good if a cast is worn two or three years In adults an early case can be arrested and cured by cast immobilization, but in more advanced cases if immobilization does not check the progress in a reasonable time total resection of the carpus is indicated followed by long immobilization and general treatment.

Tuberculous Tenosynovitis

Of the many instances of tuberculosis only occasionally does the bacillus show a special affinity for the tendon sheaths about the hand. Here it occurs usually as the only apparent lesion in the body, and often shows a low degree of virulence and a tendency to yield to curative measures. The condition is well known and has been ably described by many authors, notably Kanavel, Mason, Potts, and Marble.

Etiology The frequent incidence of tuberculous tendon-sheath involvement in those who work with cattle (such as milkers, skinners, and butchers), and with diseased cattle (such as workers in fertilizer or tallow plants), and the low virulence and tendency to involve the extremities suggest that the tuberculosis is bovine in type. Being uncommon in children it may not be milk borne. In at least six known instances the inoculation occurred through the skin of the hand, though these are too few to assume that this is the usual portal of entry Potts reported it in two cases in fertilizer workers following an indolent sore, one from a scratch in a finger by two months and the other a crushed finger by three months In my case, in a tallow worker, it followed a pimple in the skin which lasted two months

Closed trauma is of doubtful importance in determining the lesion, though claimed in a fair percentage of cases as also in other types of tuberculosis

Age incidence is greatest in the third and fourth decades and tapers off with the increasing years, the oldest being 82 A few cases start in the second decade, the young

FIG. 633 Tuberculous tenosynovitis (A and B) Case V O Ulnar bursa palm and little finger (C and D) Case H. R. Local, as shown (E and F) Case S C Ulnar bursa, palm and index finger (G) Case J H. Bilateral ulnar bursae left hand, palm and index finger

est being 11 The incidence is slightly greater in males being in the proportion of seven to five Females seem to be affected younger than males, the average age being near 30, compared with near 40 in males. The right hand is affected about twice as often as is the left, and the volar tendons about twice as frequently as the dorsal ones Rarely is it bilateral. Occupation is unimportant except for bovine contamination.

Pulmonary tuberculosis, though common, is not often accompanied by tendon sheath involvement and vice versa, until the condition becomes generalized. From a tendon sheath in a hand tuberculosis readily spreads to other parts and may become generalized It is probable that there are other original foci, but usually none are demonstrable in the case coming for treatment Recurrence after operation is likely to be in the same or other tendon sheaths, in the same or other hand, about the ankle or in the wrist joint.

Pathology Tuberculosis of the sheath and tendon often is bizarre in form, as it is in other localities such as the peritoneal cavity, depending on the stage of the disease, the type and the relation between the virulence of the germ, and the resistance of the individual Typically, it starts with a serous exudate, and later a seropurulent one, with or without rice bodies The lining of the sheath thickens and spreads to become a granulomatous fungus. Finally, there is caseation and a cold abscess forms and perforates, leaving sinuses. As an alternative, the result may be fibrosis and a final cure. In an individual case, different parts may show at the same time gradations between various stages, or there may be a tendency to form hygroma, fungus, or fibrosis.

The process starts in the tendon sheath and epitenon which thicken and vascularize giving off a thin, straw-colored exudate that infects the whole sheath When either the radial or ulnar bursa becomes infected the other does also The infection spreads along the synovial membrane as a dark red, granular fungus following the tendon through paratenon and into fascial spaces, the palmar, thenar and quadrilateral space in the forearm It follows along down the flexor tendon for the length of a digit, or may start in the digit and follow up through palm and forearm, much as do pyogenic infections though somewhat more by contiguity and peritendinous involvement. It usually starts in a sheath, and extends along the tendon to involve the lower portion of the muscle above and to the insertion below It spreads over to other tendons in forearm and palm widening its zone until the tendons of all of the digits may be affected On the dorsum over the lower forearm, carpus, and hand it gradually involves all the tendons extensors of the digits, thumb and wrist, but does not extend down the back of the digits.

At first the synovia changes from its glittering smooth appearance to a dull lusterless, thick, congested membrane gray pink or red in color and with roughness and irregular elevations of its surface. It becomes villiform and may be spotted with tubercles or coated with layers of fibrin These particles float off in the turbid fluid to form the nuclei of rice bodies. The thin fungus-like growth along the synovia thickens to vascular granulation tissue which gradually coalesces from sheath to epitenon and tendon to tendon filling the sheaths and spaces until all the tendons are imbedded in a sausage like jelly filled granulomatous proliferating mass. It extends through digit and palm or forearm, or all three It may start more on one side, but gradually extends across to the other

The infection is primarily in the synovia, and for many months the tendons do not become invaded and look clean though not glistening, when separated from the surrounding clinging fungus. It may be one to several years before the disease destroys the tendons themselves The septa of endotenon thicken splitting the tendon fibers apart and expanding the tendon which then appears dull, yellowish and red tinged. As its fibers fray apart they become invaded throughout with the granulomatous fungus until the tendon loses its consistency and is beyond repair Often it ruptures spontaneously

Similarly the tuberculous process invades and destroys the annular ligaments and surrounding fascial planes. It involves the intrinsic muscles in the hand and the lower portion of the forearm muscles, though muscle itself is fairly resistant. The ulnar and median nerves become compressed, flattened, and surrounded by fibrous tissue, but are not invaded until very late. The process may infiltrate through the ligaments to infect the wrist joint and carpal bones.

The tendon sheath or bursa may contain some, or be literally filled with rice bodies so numerous that they replace the exudate and themselves flow back and forth in the sheath like a fluid The glistening small flat blunt, melon-seed shaped bodies consist of laminated layers of fibrin deposited about villi, fibrinous masses or other degenerated tuberculous products and may contain cellular elements, giant cells and tubercle bacilli They seem to be a late product of an old lesion in those cases with fluid distention of the sheath In other cases the dark red, vascular granulations are excessive, filling all so there is no sheath cavity This may or may not be dotted throughout with tubercles. Eventually it either degenerates into caseation or else becomes organized with fibrosis

Microscopically the appearance of the fungus may be that of any granulation tissue though usually lymphocytes predomi-

nate over leukocytes Often tubercles with caseation, giant cells, epithelioid cells, and tubercle bacilli are numerous, and tuberculous ulcerations are present in the synovia, but in a small proportion of the cases even a careful search fails to find them In these the gross pathology is so conclusively identical to that of the microscopically verified cases that it seems safer clinically to be guided by the gross appearance It often happens that when guinea pig inoculation and microscopic examination have been negative the case later proves to be tuberculous. The condition described as tenosynovitis fungosum is difficult to differentiate from unverified tuberculosis.

Symptoms. The course is slow and insidious and the symptoms at first are so mild that cases are often well advanced even several years, before coming for treatment The earliest symptoms noticed are swelling pain and tenderness, weakness of grip, and limitation of motion

The swelling commonly starts in the palm or just above the wrist, and gradually forms an elongated, doughy mass, partially filling one side of the palm and the lower two inches of the forearm, and having a constriction in its part which is under the transverse carpal ligament of the wrist so that it resembles a keyhole in shape The size and shape are determined by the radial and ulnar bursae, both of which will be involved This swelling may extend down to one or several fingers The little finger is the most frequently involved and next the index. Then come the thumb, long and ring fingers in order of frequency

Often the swelling starts in a finger and extends into the palm, or it may start as a discrete swelling in the palm over a metacarpal head. On the dorsum the swelling commences above or below the annular ligament of the wrist, and gradually takes the form of the composite tendon sheaths there as it involves the extensors of the fingers wrist, and thumb

FIG 634 The calcareous deposit seen in x ray proved to be due to a local focus of tuberculosis in the sheath of the flexor tendons.

The swelling may be rather localized and firm or it may be diffuse, low, flat and soft, but it is usually fairly localized and doughy The skin is slightly edematous and only rarely reddish It does not feel hot and is freely movable. Only in the advanced cases is there induration. Slight degrees of swelling are seen by comparing the two hands. At first it is outlined by the sheaths, but later also by the fascial spaces in the palm or forearm At operation the involvement is always more extensive than was apparent from the swelling

Fluctuation or ballottement can often be felt between the swellings in the palm and forearm or finger and palm, especially when rice bodies are present These may sometimes be detected by palpation from the

feel of their peculiar granular flow Crepitus, creaking, or grating can often be felt, due to the rice bodies and the edematous folds of the sheath.

Pain, if there be any, is mild It may be described as a feeling of stiffness or lameness. There may be complaint of paresthesia, tingling, numbness, or an ache, due to pressure on the median nerve at the wrist. Slight tenderness may be present locally over the swelling Severe pain is rare. It may extend up the arm and occurs from the pressure of distention or from involvement of the median nerve.

Movements may show slight limitation early, but are usually surprisingly good considering the amount of pathology Gradually they become more and more restricted in each direction, as the tendon becomes adherent. Pressure of swelling alone may limit flexion and extension of wrist and digits. There is often a feeling of contracture. Weakness of grip is a common complaint.

Fever and general symptoms are usually absent and the patient looks wells and often has no idea of stopping work. Occasionally, the spontaneous rupture of a tendon first causes the patient to seek medical aid. Late cases show sinuses from spontaneous rupture or surgical drainage and if the wrist joint is involved there is stiffness and a fusiform, fluctuating swelling at the wrist. The carpal bones, radius, and ulna become involved, and in the fingers, joints, and phalanges.

Diagnosis

Ganglion	If the swelling is soft, flat and diffuse, tuberculosis of tendon sheaths should be suspected Aspiration of synovial jelly means ganglion
Xanthoma.	Usually more discrete and not limited to sheaths in outline
Angioma	Changes in size by position, pressure, and constriction
Arborescent lipomata	Rare
Gonococcal tenosynovitis	More active and with pain and disability often dorsal. Identified by aspiration and history
Syphilis	Other signs red and painful, and may break down and drain
Traumatic tenosynovitis	Pain, tenderness, and fine crepitations are prominent but less of a boggy swelling, follows overuse
Pyogenic inflammation	Acute and active with pain, fever and leukocytosis
Tenosynovitis fungosum.	May be identical

Treatment. DISCUSSION Tuberculosis is so often generalized that we should search for other involvement or foci, and if found should lean toward conservative treatment. In all cases of local tuberculosis general treatment should be carried out for several years rest, good food, vitamins, sunshine, and tuberculin. Local treatment is by conservative or operative means. A combination of both should be used. It is wise to postpone operating on a rapidly progressing case in the advancing or exudative stage. Here conservative treatment should be given for a short time, not long enough to stiffen, but until the process recedes and the fibrotic stage has started, thereby demonstrating the power of resistance of the patient. Surgery in active or generalized tuberculosis may hasten the progress of the disease. Radical excision of the diseased tissue, however, in uncomplicated cases has a high record for cure, in the neighborhood of 70 per cent and is in the opinion of the majority of authors the method of choice. Recurrence after surgery is frequent enough to demand that excision be followed for a reasonable time by conservative local treatment and for several years by general treatment.

CONSERVATIVE TREATMENT Conservative local treatment consists of immobilizing the part in a plaster cast and maintaining it so

for one or two years. The cast is bivalved so the limb can be exposed intermittently for roentgen therapy Streptomycin makes the process subside. In addition, treatment by tuberculin and other general measures is carried out. The disease process usually responds promptly and continues to decrease. A cure by this means requires, however, a very long time, and from the nature of a hand, if so long immobilized, there will be excessive stiffening. The large amount of diseased tissue in resolving leaves fibrous adhesions Surgery removes this diseased mass at once, and when followed promptly by conservative treatment the process subsides. There is less extension and better final function

SURGICAL TREATMENT Surgical drainage gives poor results If it does not lead to secondary infection and sinus formation, it may improve the hand only temporarily

Complete radical excision of all the tuberculous tissue should be carried out without injuring the essential parts of the hand, nerves, vessels, and healthy tendons Any piecemeal removal is quickly followed by recurrence, just as before the days of x ray therapy for cervical adenitis block dissection succeeded while gland by-gland removal did not.

The limb must first be rendered ischemic and a blood pressure band applied as a tourniquet An incision should be planned which will lay open the whole length of the diseased parts and still will not make flexion contracture In the finger it is mid lateral and in the palm a wide L shape, approaching the wrist in a curve so that in crossing it will parallel the wrist flexion creases and then sweep up the ulnar side of the forearm The annular ligament of the wrist is severed at its ulnar end and laid over Dissecting in the palm, one enters along the fourth ray through the watershed, so to speak, between the two nerves On the dorsum a curved incision, roughly bayonet-shaped, is used, starting on the dorsum of the thenar eminence, paralleling

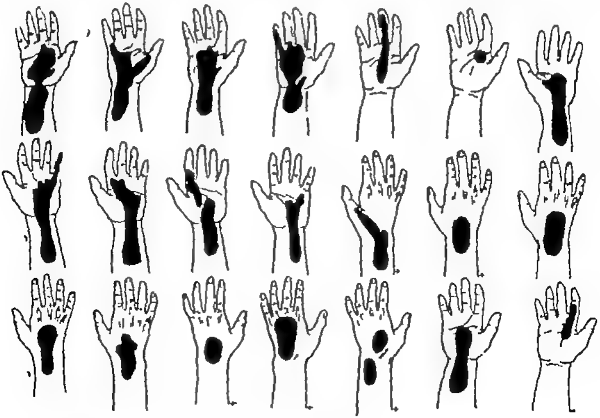

FIG. 635 Locations of the lesions in the 21 cases of tuberculous tenosynovitis reported. Of the six marked with + the pathology seemed to be definitely that of tuberculosis, though the pathologist failed to find tubercles or germs of any kind.

FIG. 636 Primary luetic chancre on long finger. Large axillary gland present.

the creases of the wrist, and running up the ulnar side of the forearm The branches of the radial nerve are protected

On incising the deep fascia the large, fungating mass presents The dissection commences at one end and one side, and is carried thoroughly and systematically down the full length and from one side across to the other Not one bit of diseased tissue should be allowed to remain It is impossible to remove the great mass of granulation proliferated sheath without incising into it, for as tendon after tendon is encountered an incision must be made to the tendon, so the diseased thickened tissues may be peeled off from it by sharp knife dissection Most tendons will be found to be smooth and uninvaded but some will be ragged and thin and will need removal. The distal remaining end can be transferred into an adjoining tendon, or rarely a tendon graft may be placed using a clean set up when working on the donor area.

If in a finger the surrounding tissues are involved it is better to amputate it. Diseased parts of muscles should be excised and also of annular ligament and other fascial or ligamentous tissues. The diseased tissue is followed as it creeps along the tendon to as far as it extends, and is removed. The wound is then gone over carefully, removing with curved scissors any bits of diseased tissue that may have been overlooked, and the tendons are cleaned of tabs. The wound may then be daubed with weak iodine solution to provoke inflammatory reaction and then rinsed thoroughly and copiously with normal salt solution to remove at least some of the escaped bacilli. After removing the tourniquet and ligating the vessels with Nos. 000 and 00000 catgut, the wound is closed without drainage. A pressure bandage and a half cast of plaster are applied in the position of function. Streptomycin should be given during and after operation as a cleanup of the bacteria set free.

Partial splinting for a few months and x ray treatments are then carried out, and general treatment is kept up for several years If on periodical inspections there is any sign of recurrence, conservative local treatment applied at once usually brings prompt response while the process is yet young. It is a surprise to see the amount of movement that is regained after such complete dissection and thorough removal of tendon sheaths. The hand usually moves better than it did preoperatively

Report of Cases. The following compilations are from my personal series of 21 cases operated upon. There were 12 males and 9 females, the average age of the males being 40 and of the females 34 The youngest patient was 11 years old, the oldest 64 Five had contact with cattle two in tallow works with tuberculous cattle, and the others a milker, a dairyman, and a slaughterer Five gave history of trauma, and of these one tallow worker had an open sore on a finger three months before the tendon sheath of that finger became involved, described as a pimple on the radial side of the proximal segment of the long finger indicating direct infection from the tuberculous cattle.

Patients have had symptoms before coming for treatment for the indicated time

Months	1	1½	1½	2	2	3	3	5	6	7	15
Years	1½	2	2	3	3	3	4	4	9	12	

The usual symptoms complained of in order of their appearance, were swelling

pain and tenderness, weakness of grip, limitation of motion, contracture, crepitation, and spontaneous rupture of tendons. Thirteen were in the right hand, compared with 8 in the left, in one case both hands being involved. There were 14 cases of volar tendons and sheaths, compared to 7 on the dorsum. Of the latter, 7 were of the extensor tendons of the fingers, 4 extensors of the wrist, and 2 extensors of the thumb Of the volar involvement 9 were of both radial and ulnar bursae, 11 of the palm, and 8 flexors of the digits These were in the long finger 7, index 5, little 4, ring 4, and thumb 5 The extensor carpi ulnaris was involved once.

Rice bodies were present in 10 and absent in 11

Pathologic reports declared tuberculosis in 15, but failed to confirm the diagnosis in 6, though the gross pathology was identical with that of tuberculosis. In one case repeated search finally revealed a tubercle, and in one guinea pig inoculation with fluid was negative but later microscopic section was positive. In some of the positive cases there were the following unusual findings

Exudate with appearance of cream and butter, thin yellow pus, granules like cooked yellow cornmeal, lime of consistency of paste that showed by x ray

In none were there apparent lesions other than local. In one case a finger was amputated and in another the wrist was involved. In all, radical excision of diseased tissue was carried out. Postoperative results were as follows

Fourteen were cured, one could not be traced, and in six there were recurrences. Of these, two died from generalized tuberculosis—one in three and the other in five years. Of the other four recurrences, one involved the same tendon but by reoperation was cured. Another recurred in the same tendon but was cured conservatively, and a third recurred in other tendons but was also cured conservatively The remaining recurrence was in a wrist joint, which was cured conservatively with ankylosis.

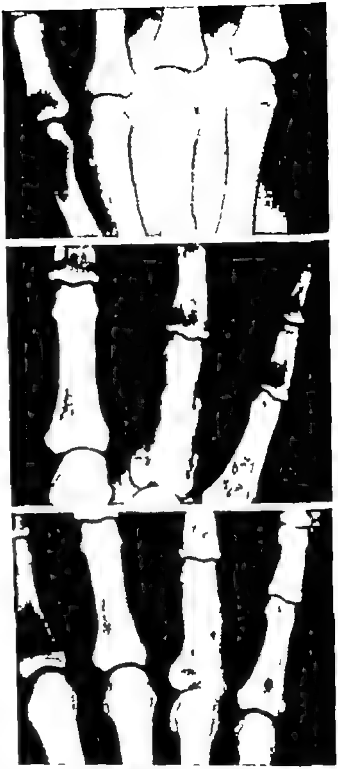

FIG. 637 Syphilitic dactylitis.
(*Top*) Proliferation of periosteal bone
(*Center*) Diffuse osteitis.
(*Bottom*) Same a year later after treatment.

SYPHILIS

Syphilis occurs in the hand in many forms, only a few of which need be mentioned here.

A chronic sore on a finger should suggest chancre and making a dark stage ex

FIG. 638A. Charcot's joint. Two views of wrist.

amination Hallop claims that .25 per cent of chancres are on the hand, and of these about nine out of ten are on the fingers, in half of which it is the index. The usual site is on the dorsum. As a hangnail may be the point of entry the chancre may be mistaken for a paronychia.

In the tertiary stage there may be lesions of skin, paronychia, tendon sheath, bones, and joints. Tendon-sheath infection is rare being reported as of the tendons on the dorsum of the wrist bilateral, painless, and with gumma formation.

In bones the typical lesion is that of proliferation of the periosteal bone and increased density This may show in phalanges and metacarpals. It also occurs as diffuse osteitis or osteomyelitis in phalanges and metacarpals, there being not only surface thickening but also gummatous, destructive patches throughout the shaft.

The dactylitis, like that from tuberculosis, shows as a swollen, boggy, spindle-shaped finger, but is easily distinguished by x ray Gummatous osteomyelitis may break down and have discharging sinuses and some sequestrum formation Pyogenic infection is added From involvement of joints ankylosis results, and from damage to epiphyses the fingers on growing may become distorted.

The wrist joint may be involved with villous synovitis, destruction of cartilage, and gumma formation in the underlying bones. With acute onset, chronic painful synovitis and hydrops follows, limiting motion and function.

The wrist and metacarpophalangeal joints may undergo the painless extensive destruction of Charcot.

TULAREMIA

Etiology Tularemia was first found in Tulare Co, Calif though rare in Tulare Co, it exists over all the United States and in Alaska In this general disease the initial lesion is commonly in the hand, though in the glandular, gastro-intestinal and typhoid types there may be no initial lesion. Throughout our western states, the native rodents and some birds and also their parasites, ticks, and deer flies carry the disease Rabbits are the chief offenders. Those who skin and handle these animals may inoculate their fingers and hands through some slight wound with the *Pasteurella tularensis* a small, rod shaped bacterium that changes to a coccus form, or may acquire it by the bite of a fly or tick.

Pathology First, there is a red papule or granuloma in a small zone of inflammation. In a week the center necroses and is extruded, leaving a punched-out ulcer with

raised borders, a necrotic base, and an indurated, red periphery. The pus is scanty and contains the bacteria. Lymphangitis and lymphadenitis are present, and in half the cases the glands suppurate. Multiple lesions of necrosis may be found in any organ.

Symptoms. After one to six days of incubation, starting acutely like influenza, with necrotic areas in liver and spleen. The Foshay intradermal test is reliable from the second day to 15 months. A blood culture can be obtained during the first week. Agglutinins are demonstrable after 12 days.

Treatment. Surgery is definitely contraindicated in all the acute lesions, as it spreads infection. Kavanaugh advises that

Fig. 638B Primary cutaneous lesions in tularemia
(A) A primary papule on the seventh day
(B) A primary papule showing beginning liberation of the necrotic core on the fourteenth day
(C) A primary ulcer after liberation of the necrotic core on the twenty first day
(D) A primary ulcer on the forty second day. (Courtesy Kavanaugh, C N Arch. Int. Med., 55 70 1935.)

the initial lesion if any rapidly forms, and also painful adenitis occurs. General symptoms are chills, fever, leukocytosis, pain in head, back, and limbs, vomiting, and prostration. All may subside in a few days, and may recur but finally leave in two or three weeks. Some persist with remittent fever. The pneumonic typhoid and meningitic types are often fatal, but the average mortality is about 4 per cent. Immunity is conferred.

Diagnosis. This is made from the history of contact, identification of the bacteria in the smear, and by guinea pig inoculation—the pig dying in two or three days

Fig. 639 Suppurating adenopathy in tularemia four weeks after onset. (Courtesy Kavanaugh C. N Arch Int. Med., 55 71 1935.)

Fig. 640 Photomicrograph of *P tula rensis* in dextrose broth blood culture after 12 days. (Courtesy Lufkin, N H., and A. E. Evenson Jour Lab and Clin Med. 22.348 1936–1937)

Fig. 642 *Bacillus anthracis* with spores carbol fuchsin and methylene blue stain (× 1000) (Fränkel and Pfeiffer) (Courtesy Jordan and Burrows Textbook of Bacteriology 13th Edit., W B Saunders Co., Publishers, 1941)

an old broken-down gland may be excised, followed by closure. *General supportive* bed treatment is used The serum of Foshay seems to be beneficial, and also transfusions of convalescent serum Streptomycin is bactericidal and bacteriostatic to P tula rensis. It has an immediate effect in relieving the symptoms Forshay states that *there is no evidence to date that a case of* moderate severity cannot be cured by the following .5 Gm streptomycin per day for from two to six days

Anthrax

Etiology *Bacillus anthracis* found on hair, hides, and feces of most domestic animals inoculates man by being rubbed *into some abrasion—frequently on the* hand Infection also occurs through the respiratory and alimentary tracts.

Pathology A malignant pustule develops, easily recognized by its typical appearance. Starting as a furuncle, in 24 hours this develops a vesicle and red areola. On rupturing on the fourth day there is a little dark, bloody serum and soon a gangrenous, black base. There may be several of these grouped on an angry, red, edematous swelling, and about the pustules are *many minute silvery vesicles.* The disease may rapidly spread to pneumonia endo-

Fig. 641 Anthrax carbuncle showing the gangrenous crust surrounded by a zone of inflammation in which are vesicles filled with a serohemorrhagic fluid. (Courtesy Hart, D Lewis Practice of Surgery after Lexer Bevan, 5 155 Hagerstown, Md., W F Pryor Co., 1943)

carditis, meningitis, and septicemia, in which case it is usually fatal

Symptoms After incubation of one to three days the pustule, which may itch at first but not pain, breaks down in 10 to 15 days and heals in three weeks General symptoms start on the third day fever, prostration, delirium. Severe cases may die in four to seven days, but most are mild and recover *Mortality* is 16 to 20 per cent

Diagnosis. The history and lesion are typical and the pustule teems with spectacular chains of anthrax bacilli which, when inoculated in a guinea pig cause death in 24 hours.

Treatment. Prophylactic cattle control is best. Surgery is contraindicated as it spreads the disease. The serum as recommended by Regan, which is the treatment of choice is given locally and generally This, combined with neosalvarsan, seems to help Penicillin up to 100,000 units daily gave immediate and definite response (Murphy) Ellingson et al cured 25 consecutive cases with 1,000,000 to 4,000,000 units of penicillin Organisms left most of the wounds, and the three cases in which they were in the blood stream, in 24 hours

Fig. 643 Oriental sore of two months duration appearing three months after exposure. The ulcer is covered with a firmly adherent, dirty yellowish crust about 1¼ inches in diameter Surrounding the crust is a reddish, firm, infiltrated zone covering twice the area of the central crust. There is a thin serous discharge, and the ulcer bleeds easily on traumatization. The lesion is painless and there is no enlargement of the associated lymph nodes. Microscopic section of the skin showed edema, cellular infiltration, Langhans' cells, and Leishman's tropica protozoa (Courtesy Hart, D Lewis' Practice of Surgery 5 217 Hagerstown Md., W F Pryor Co., 1943 from New York Med. Jour., 116.367 1922)

Glanders

Etiology *Malleomyces mallei,* a small, rod shaped bacillus, is found in the nasal mucus of infected horses, mules, and donkeys It may enter an abrasion on the hand causing an initial lesion there of the disease called farcy in man It may also enter through the nose.

Pathology The granulomatous, phlegmonous lesion with a red zone about it develops on the hand and breaks down to ulceration There are small vesicles and pustules about it, and lymphangitis and adenitis are present. The ulceration may extend into muscles or uncover bones, and sinuses may form discharging yellow, oily, necrotic material At a distance lungs, peritoneum, skin, joints, and bones may be involved.

Symptoms. After an incubation of two to five days, acute general symptoms of

chill and fever may precede the granuloma. There is nasal inflammation, head and backache vomiting diarrhea, and malaise. The fever is intermittent, or like typhoid. In the second week painful nodules form

FIG. 644 Smear preparation from oriental sore. The ring like bodies with white central portions and containing a larger and smaller dark mass are the micro-organisms. The dark masses stain lilac, and peripheral portions pale robin s-egg blue, with Wright s stain. (Courtesy Hart, D Lewis Practice of Surgery 5 219 Hagerstown, Md., W F Pryor Co., 1943)

in skin and muscles anywhere, and form sinuses Acute cases are fatal in two or three weeks Chronic cases may last for weeks, months or years and later flare up as acute There is a 50 per cent mortality

Diagnosis The bacteria from the lesion may be identified by smear or intraperitoneal guinea pig inoculation causing orchitis in two or three days. There is a mallein test both subcutaneous and ophthalmic, and agglutination and a complement fixation test.

Treatment. The only treatment is prophylactic by animal control

Gonorrhea

In the hand the gonococcus transmitted by the blood causes tenosynovitis and arthritis of the wrist and finger joints.

Pathology Tenosynovitis is acute or chronic. The sheath is red thickened and tender with inflammation, and contains at first serous then fibrinous and finally pur lent fluid which is translucent, grayish, an greasy Occasionally the tendon become involved.

The joints are acutely or chronically i flamed, are painful, tender, and swolle and contain from serous fluid to pus. Bot the synovia and especially periarticula tissues are affected In the wrist joint, which is a common site, gradually the carpal bones may become porotic and disintegrate and in any joint the inflammation may subside or may leave any degree of ankylosis.

Symptoms. Tendon sheaths and joints become inflamed in the third week or even when the infection has become chronic. The onset is abrupt, with pain and moderate fever The swelling is uniform and tender, and the skin is smooth and red The joint is held slightly flexed and immobile as there is pain on movement. When the tendon sheath is involved movements are inhibited. Untreated, these conditions last weeks or months.

Diagnosis There is the history of gonorrhea and at times of polyarthritis On suspicion the sheath or joint should be aspirated. The gonococcus is identified from the fluid by smear or culture.

Treatment. Locally, the sheath or joint is aspirated and the limb is splinted, traction being used in the case of arthritis Drainage is done only in case of progressing abscess. Sulfathiazole and penicillin systemically are remarkably effective Penicillin should be instilled into the joint of a strength of 2000 U per cc. The joint should be given rest, aspirated and splinted Traction prevents joint damage Drainage is used only in progressing abscess

Leishmaniasis

Long known as oriental sore, Delhi boil, or tropical ulcer from about the Mediterranean to India, it is also being found in the United States. *Leishmania tropica* is a spindle-shaped, flagellated protozoa that is probably transmitted by a sand fly to exposed parts—especially the dorsum of the hand—producing a sore. There is at first a papule which is red, raised, indurated

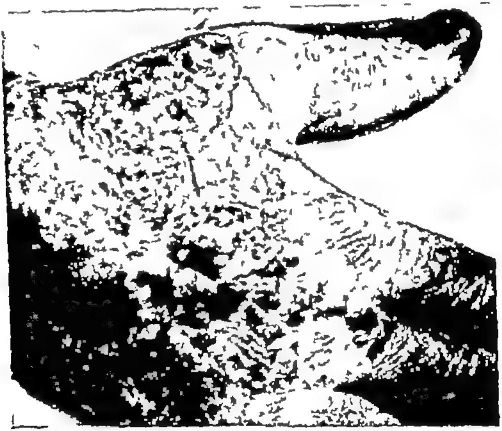

Fig. 645 Actinomycosis of the hand. The infection had been present for II months and came on following a laceration which was treated with tobacco removed from the mouth. The original injury healed promptly Two or three months later small abscesses appeared about the scar and these spread, despite the usual surgical treatment of incision and drainage, until most of the dorsum was involved. The surface of the affected area was irregularly nodular and crusted, and showed areas of ill-defined scarring. The ulcers were irregular and there were numerous subepidermal abscesses, some of which had opened and were discharging The area was tender the skin was bound down, and considerable induration was present but no lymphatic involvement. The patient was treated with large doses of potassium iodide internally and 25 per cent aluminum acetate and 10 per cent ammoniated mercury ointment locally Three x ray treatments were given after three months healing was complete. The ray fungus was demonstrated in the pus. (Courtesy Hart, D Lewis' Practice of Surgery 5 202 Hagerstown, Md., W F Pryor Co., 1943)

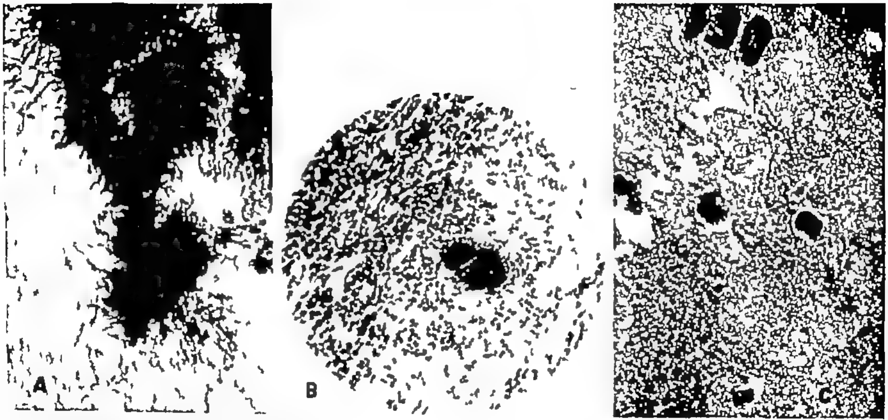

FIG. 646 (A) A sulfur granule (Gram's stain × 400) this is the typical ray fungus rosette. The conformation of the twisted mycelial threads is shown.

(B) A number of Actinomyces colonies surrounded by leukocytes.

(C) A Gram's stain of a sulfur granule, showing the intertwining mycelial threads of the Streptothrix (× 400) (After Wangensteen, O H. Annals of Surgery 104 755 No 4 1936.)

and about an inch in diameter In several months this breaks down to a crater which may last for years and leave a depressed scar The ulcer teems with the protozoa, many of which are intracellular, and these can easily be seen on a smear and culture Treatment has been by tartar emetic which is specific. Ball and Ryan in our African campaign successfully treated 500 cases with another preparation of antimony, neostam, intravenously 05 to 2 Gms three times a week until cured, the total amount of drug averaging 1 14 Gms A cure may be effected in about a week by injecting berberine sulphate (Orisal) in four punctures about and under the ulcer, thus killing the organism and producing fibrositis about the local site.

Milker's Granuloma

This is merely a chronic red, painful, granulating, discharging nodule occurring on the hand of a milker or one who works with cattle. It is caused by the presence of a cow's hair which, being provided with barbs, works in, remaining as a foreign body On removing the hair and draining or excising the nodule, the wound heals.

Another entity known as milker's nodule occurs on the hands of milkers of cows that have crusted sores on their udders Starting as an erythematous papule the lesion develops to a bluish red nodule, becomes depressed centrally and then granulates and heals in from four to six weeks It is self limited and resembles variola, but is probably from a different virus (Becker)

Fungoid Infections of Hand

Actinomycosis

Etiology Infection from *Actinomyces bovis* or ray fungus occurs rarely on the

Fig. 647 Blastomycosis of the hand. (Courtesy Montgomery F H., and O S Ormsby Arch. Int. Med., 2 5 No 1 1908)

dorsum of the hand from mouth contact. Being a saprophyte on grains and grasses, the fungus lodges in the mouth in tonsils and about teeth, secondarily invading the jaw, neck or other parts Abrasions or open wounds of the hand have been infected by the ray fungus from cattle, in which it occurs as lumpy jaw, and from a mouth carried by a tobacco-juice poultice. It is found throughout the world

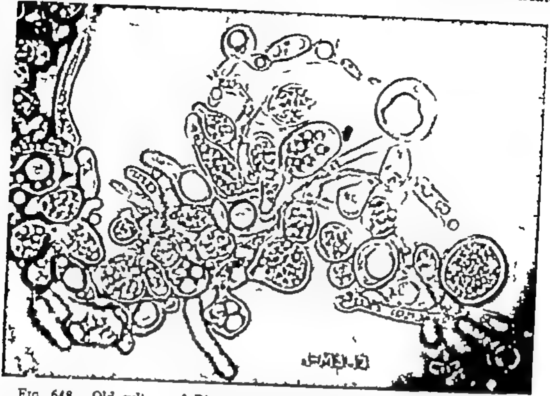

FIG. 648. Old culture of Blastomyces showing large round bodies and short, thick mycelium containing spore like bodies. (Courtesy Montgomery F H., and O S Ormsby Arch. Int. Med. 2 25 1908)

Pathology Affecting the superficial tissues, there is a raised granuloma resembling that of tuberculosis or syphilis over which the skin is tight and of a livid purple red Remaining for months as an indolent nodule with typical woody hardness, it eventually breaks down to a mass honeycombed with channels and sinuses exuding thin pus It may involve the underlying bone and may cover the whole dorsum of the hand There may be history of peridontitis

Symptoms. After an incubation period of weeks or months the lesion appears It is painless and without much in the way of subjective symptoms, but lasts months or years.

Diagnosis In the pus are tiny, sulfur yellow granules which when treated with 25 per cent potassium hydroxide show the ring of clubs typical of the ray fungus

Treatment. Early excision has been successful. It should be wide and thorough, and in some cases cauterization curetting and draining There is often recurrence in the scar Surgery should be supplemented by exposures to x ray using filtration and given over a long period to maintain excess vascularity Sulfonamides merely inhibit the fungus and act on secondary invaders. Potassium iodide has long been used, but with less effect Penicillin helped about half of the cases. Sulfodiazine and penicillin should be used in large doses over a long period

Blastomycosis

Etiology Found over the United States, Canada, and elsewhere is a disease caused by yeast, Blastomyces or Oidiomycetes,

FIG. 649 Sporotrichotic lesions which gradually came on as nodules along a cord which followed the course of the lymphatic drainage. These nodules all went on to ulceration with discharge of a gelatinous purulent material (Courtesy Hart, D Lewis Practice of Surgery 5 196 Hagerstown Md., W F Pryor Co., 1943)

which is manifested by chronic spreading dermatitis, a pulmonary condition, or a fatal systemic involvement The dermatitis often without systemic involvement is found especially on exposed parts, of which the hand is a frequent site Starting from a slight break in the skin or no injury, it spreads broadly in patches by contact or by blood stream to new patches

Pathology The lesion, starting as a red papule or papulopustule, spreads to a patch an inch or more across and three-eighths inch high, which is quite rough and irregular and covered by a thick crust from under which oozes a glairy, mucopurulent discharge. The patch spreads peripherally and heals in the center Removal of the crust exposes a very rough, uneven, papillomatous surface with wart like papillae, cauliflower excrescences, and many ulcerations, miliary abscesses, and sinuses The sloping sides of the borders are purple, dark red and indurated Adjoining lymph glands are usually not involved Giant cells are numerous in the granuloma and the pus is full of leukocytes and budding

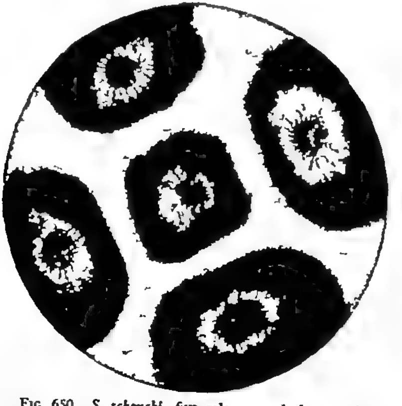

FIG. 650 *S schenckii* five colonies each from a single spore planted on a maltose agar plate. (Courtesy Benham R. W., and B Kesten Jour Infect. Dis., 50 441 1932 University of Chicago Press Publishers.)

yeast fungi. These show best in 15 per cent potassium hydrate, are round or oval, and have a refractive capsule and a diameter of 3 to 30 microns.

Symptoms. The onset of the cutaneous form may or may not be with pulmonary symptoms like "a cold," and the lesions may persist chronically for many years, leaving great cicatrices. They are usually painless, though there may be pain in the deeper abscesses. The systemic type with fever and general symptoms involves the deep organs and bones and has high

tality

Diagnosis. The lesion is char

and the fungus is readily found

Treatment. Small lesions may

cessfully excised Prognosis is

treated with large doses of

FIG. 651 *S schencki* a low-power view of a culture on a slide (Courtesy Benham, R. W., and B Kesten Jour Infect. Dis., 50 442 1932 University of Chicago Press Publishers.)

dide There are some favorable reports from treatment with carbosulfate and x ray

Sporotrichosis

Etiology *Sporothrix schencki* a fungus, causes a local skin disease found usually on hands and forearms. More common in rural districts, it is seen especially in farmers and gardeners who work with plants and become inoculated with the fungus through some trivial wound It is also known in horses dogs, and rats, and has been a bite and also from one and from the

to

Pathology is of the skin

very rarely

g bones Starting as a

red

weeks this ulcerates or forms a cold abscess. After a remission of a week or month it extends along the lymph vessels, forming an indurated cord along which as a chain are many firm nodules similar to the first. These are subcutaneous but later break down, attaching to the skin and forming abscesses, sinuses, and ulcers The ulcers are violet tinged, brownish red in color, with indurated margins The picture with gummatous lesions along an indurated cord is quite typical Occasionally a lymph gland is involved and progresses to abscess. The discharge is first clear but later gelatinous, purulent, and contains eosinophils. The tissue is granulomatous and with giant cells, but in it there is difficulty in finding organisms. There may be an eosinophilia of 8 per cent.

The fungus is readily cultured, showing long threads along which and on whose short branches are clusters of small oval bodies called conidia. Only these, and not the threads, are found in tissue.

Symptoms. The lesions are painless and indolent, the disease being chronic for many months until treated, and though the onset is sudden and febrile the subsequent course is devoid of fever or general symptoms.

Diagnosis. With the history of occupation and the typical appearance of the lesion, a culture should be made. This shows the organism. Also the blood responds to an agglutination and a complement fixation test, and there is prompt clinical response to potassium iodide.

Treatment. Incisions make the condition worse. It is sensitive to the sulfonamides. Potassium iodide is specific, resulting in healing in two weeks. It should be continued, however, six weeks longer to prevent recurrence. Abscesses may be aspirated and ulcers are treated with Lugol's solution and dilute tincture of iodine.

Coccidiosis

Etiology Coccidioidomycosis affects the hands in only a small proportion of cases, either primarily through a break in the skin or secondarily in this unusual disease which in many respects resembles tuberculosis It is found in California, where it is fairly common in the San Joaquin Valley Also a few cases have occurred in Arizona Locally a large percentage of the inhabitants react to the coccidioidin test (similar to tuberculin) without knowledge of having had the disease Most respiratory infections from it recover in from four to six weeks Erythema nodosum is a common manifestation The course may be acute and short or may run on to the granuloma stage. Some cases show pulmonary, cutaneous, and osseous lesions running a chronic course from mild to severe, and in others the disease is generalized in which case it is fatal.

Pathology In hands are verrucous skin lesions, subcutaneous abscesses, and granulomatous nodules which later become irregular indurated ulcers In the *secretions*, cleared with 15 per cent potassium hydroxide, are seen many spherical bodies as large as 15 to 30 microns with refractive capsules and full of spores. The culture on glucose agar is fluffy white.

Diagnosis. In an indolent tuberculous-appearing lesion, organisms should be searched for and easily found. The coccidioidin cutaneous test is confirmatory

Treatment. Aside from excision and drainage, the treatment is general, as in tuberculosis. Potassium iodide does not help

Erysipeloid

Etiology The fungus *Erysipelothrix rhusiopathiæ* enters the skin of the hand through a trivial wound, causing a local skin eruption somewhat resembling erysipelas, which seldom reaches above the wrist and is usually self limited, though a case of nine years chronicity has been re-

ported. It is usually contracted handling fish or shellfish, though also from swine (hence, the name swine erysipelas), meat, poultry, game and cheese.

Pathology A dark bluish red, slightly swollen area with an irregular papular border gradually spreads over a considerable area of the hand or fingers, sometimes including the volar surface as it heals centrally There may be red lines and adenitis

Symptoms. After an incubation of from two to 15 days the disease runs its course in two or three weeks, but does not confer immunity Symptoms are slight consisting of itching, burning moderate pain, and slight fever and malaise

Diagnosis. There is the typical appearance and history, and by smear and culture the thread like organism can be identified *There is also an intradermal test* showing a wheal in 24 hours.

Treatment. Little if any is needed. Cold compresses give relief Sulfonamides are not effective, but penicillin acts within 48 hours.

Specific Paronychia

In chronic paronychia often multiple with redness swelling, little or no pus, and poor deformed or detached nails, search should be made for *Epidermophyton Trichophyton* (*fariform* or *gypseum*) and *Monilia* The organisms of the above fungi may be found in skin scrapings and in pieces of nail dropped in 70 per cent alcohol to kill bacteria and cultures on honey agar Detached nail should be clipped away Ammoniate of mercury ointment in gauze kept packed in next to the nail may cure without the necessity of avulsing the nail Ammoniacal silver nitrate applied twice a week, each time making cuts in the nail with a scalpel, penetrates and, by rendering tissues and debris unfit for food for bacteria, cures the condition. *Monilia albicans* is the yeast like organism of thrush or vulvovaginal mycosis and is prevalent in hands long soaked in water and may also be present on the dorsum of the webs It responds to carbosulfate, and can be found microscopically It shows in culture grown at room temperature as budding yeast with rudimentary mycelia.

Syphilis is another cause of chronic indolent paronychia, multiple and with nails irregular, shedding, and replacing. Also chancre may appear as a paronychia.

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15

The Hand in Industry

INCIDENCE OF INJURIES TO HANDS
PROPHYLAXIS
CARE OF INJURED
PERMANENT DISABILITY
WORKMEN'S COMPENSATION
REHABILITATION

INCIDENCE OF INJURIES TO HANDS

In this mechanized industrial age much of the work is done with the hands, either directly using tools or controlling machinery Therefore, the hands which do the work are more frequently injured than any other part of the body In workmen's compensation insurance by far the largest number of injuries and the greatest expense are incurred from hands Of all industrial accidents those of wrists, hands, and digits amount to over one-third in number and about one-fifth of the cost Statistics vary according to industries, in some reaching to as high as over one half in the number of hand injuries. The importance of the hand in industry is shown in the following statistics

Statistics Reports of the Industrial Accident Commission of the State of California for the years 1936 to 1941 are of 420,762 cases, of which 52 per cent were of the upper extremities Assuming that arms alone constitute 11 per cent, this leaves 41 per cent of injuries to hands and digits. From this Commission are also available statistics on the proportion of hands and digits injured in the years 1914 to 1921 inclusive (omitting 1918) See table at top of second column.

The National Safety Council for the years 1932 to 1934, compiling the reports of labor commissions of four states gives in

Year	Cases	*Hand and Digits Per Cent of Cases*	*Wrist Hand and Digits*
1914	60 241	32 0	
1915	65,741	33 5	
1916	92 513	33 5	
1917	107 402	31 0	
1919	57 991	34 5	36
1920	69 813	30 5	34
1921	61 723	28 9	33

juries to the upper extremity 44 per cent of cases and 32 per cent of expense. The following statistics are from this Council as given in Accidental Facts, based on reports from four and finally seven states

		Per Cent of Cases	*Per Cent of Expense*
1932	Hand and digits	33	19
1933	Hand and digits	32	
1934	Hand and digits	33	18
1935	Hand and digits	32	19
	Arm	11 2	13
1938	Arm	33	17
1939	Arm	28 3	
1940	Hand and digits	30	19
	Arm	9	11
1942	Hand and digits	30	19
	Arm	9	11

Summary Injuries of hands and digits—33 per cent of cases and 18 per cent of total expense Hands, digits, and wrist—36 per cent of cases.

The average expense for each injury of the hand and digits was one-half that of each of all injuries.

The Oregon State Industrial Accik Commission reports for the first six of 1942 that of 26,673 cases the

injury was of the eye, 5,944, then came hands and fingers, 4,863, then fingers alone, 3,377 Of 2,299 fractures there were of wrists 94, hands 62, and digits 431, of 129 dislocations there were of fingers 10, thumb 6, wrist 4, and hand 1

Iselin gave the following figures of incidence of hand injuries

State Railways, France, 46 per cent of total compensation paid for hands; Central Bureau of Workers' Accident Insurance, in Bohemia, in 1929, 40.8 per cent of cases with 30 per cent of expense. Bata Shoe Factory at Zlim, in 1932, 62 per cent of cases.

Incidence of Permanent Disability Of all permanent disabilities in compensation, 55 per cent are due to injuries of the upper extremity

In California, in 1915, of 1,264 cases of total disability, 40 were of hands and 750 of digits, totaling 790 cases or 62 per cent of all

The ratio of cases of temporary to those of permanent disability in hands is 9 to 1 The following is figured from the statistics of seven states as given in "Accident Facts," 1942 Of all injuries (232 068) 21 per cent resulted in some permanent disability, and 9 per cent of the total in that of hands and digits Of these 49,866 permanent disabilities, 45 per cent were of hands and digits.

Type of Accident. The major source of hand injuries is from operating machinery, the use of hand tools and the handling of objects. Working on and with machinery is the greatest factor Injury is more likely to happen when the machine sets the pace than when one works at one's natural speed Moving machinery is especially dangerous, such as power presses, gears, rollers belts and pulleys revolving shafts and power saws The handling of sheet metal, metal plates wire cables, glass, lumber and rough and sharp objects predisposes to lacerations and punctures, which often result in infection. The use of gloves in this work is protective. Arms are injured more by falls Cuts and bruises are especially common in hands. Injuries from machinery tend to give permanent partial disabilities, and from rough objects, hand tools and falls, temporary total disability In the report of the Industrial Accident Commission of California for 1919 of 2,927 injuries of hands and digits 2,220 were from cuts and bruises. In the 1940 report of the Industrial Accident Commission of Pennsylvania, three out of five finger injuries were from lacerations and also one-half of those of the hand and palm. There are some industries in which only a small percentage of injuries are to hands and digits, such as stevedoring logging and mining. The following table from 'Accident Facts" of 1947 compiled from seven states, mostly for 1938, relates the type of injury with the permanent disability

	Arm	*Hands*	*Digits*
Total cases, 49,866	4 437	2 972	19 702
Machinery	11 per cent	25 per cent	39 per cent
Handling objects	13 "	20 "	26 " "
Falls	50	14 "	5 " "
Using hand tools	2 " "	8 "	10 " "
Vehicles	13 "	8	7 " "
Falling objects	3	4 " '	4 " "
All other types	8	21 "	9 " "

Cause of Disability Fractures of phalanges and metacarpals are particularly disabling because of stiffening of the joints and adherence of the tendons. Severance of flexor tendons in fingers and hands generally results in disability Crushes and sprains stiffen joints, but infection, either primary or added to the injury, is a great additional cause of disability Carpal injuries often result in limited motion, lameness, and weakness of grip

Infection Factor. From compilations by the National Safety Council we learn that of all injuries one in ten becomes in

fected, but of all hand injuries one in four Of all infected cases 49 per cent are of digits. Twenty-eight per cent of all hand injuries become infected and 21 per cent of injuries of digits. Roughly one in five hand injuries becomes infected, a frequency four times that in other injuries Of 3,400 infected compensation cases in the state of New York in 1932 to 1934, 72 2 per cent were of hands and fingers The average compensation expense of a hand injury is $93 00, but it is $188 00 (or double) if the wound becomes infected.

Hand infections cause from 5 to 9 per cent of grave disabilities in industry, and usually start from trivial injuries that report for medical treatment too late Couch expresses it well in reporting on 15,000 cases of severe hand infections in one year in the Province of Ontario In these the cost of injury was increased 500 per cent. There were 25 cases of permanent disability and 5 of death About one-half had some disability For the 1 470 cases of temporary disability there was an average loss of 30 days, $75 00 for compensation, and $38 00 for medical expense. The total annual cost from these infected hands, including those of permanent disability and the five deaths, was 48,000 working days and $250,000 00, which were unnecessary and preventable.

PROPHYLAXIS

Safety Movement. A movement for safety in industry was under way by 1911 with the advent of compensation laws The American Museum of Safety was established in New York, and in Chicago the next year the National Safety Council was started In 1915 came the American Society of Safety Engineers, and in 1918 local safety councils began to appear in various cities There were then many other safety organizations. By the end of the First World War the general practice of safety was a reality, and as a result annual industrial deaths dropped between 1913 and 1936 from 35,000 to 18,000 At present, the safety movement is well organized and controlled There are federal, state, and city laws, and statistics are kept by the U S Department of Labor, and the many state labor commissions The National Safety Council, local councils, and many associations are in action An Industrial Safety Museum is operated by the State Department of Labor in New Jersey, and safety museums are now in many states Interest by industrialists was accentuated when the Travelers Insurance Company, in 1926, showed that for every accident there are hidden expenses for replacement of machinery, break in continuity of work, etc., that amounts to four times the expense of the resulting injury to persons. It is of interest to know that in California, as the result of advance in safety, though the population has from 1914 to 1943 almost trebled, the death rate from accidents is the same even though the proportion of it from vehicles has increased.

Principles of Installing Safety The philosophy of accidents is well organized by Heinrich He has shown that for every accident there is either an unsafe personal act or a special mechanical hazard, or both. By establishing a fact finding system, recording, analyzing and card coding every accident, the causes may be run down and the correction carried through. The record keeping and analysis is under a supervisor and the fact finding is done through the foreman Over the supervisor is a safety committee which meets regularly Establishment of the system is done by a safety engineer Periodical inspection of personnel, machinery, and tools is essential. In a small plant the employer must do all these himself It is claimed that with modern methods most accidents can be eliminated and the insurance rate reduced. An example of tabulating on the Heinrich Cause Code Card, adopted in the manual

of Industrial Accident Statistics, United States Department of Labor, is as follows

		Accident
1.	The agency	Lathe
2	The agency part	Gears
3	The unsafe mechanical or physical condition.	Unguarded
4	The accident type	Caught in between
5	The unsafe act	Removing safety devices
6.	The unsafe personal factor	Willful disregard of instructions

Analysis of the cards shows that 88 per cent of accidents are from unsafe acts, as in the above example. Prevention is by training and disciplining the workers to eliminate these acts, and by guarding machinery against mechanical hazards. Having educated the worker, he must be compelled to observe the precautions. An employer has the right to direct how the work is done and it is up to the employer to enforce the use of safe methods. Psychic twists of the worker, such as bravado, carelessness, stubbornness, etc., need control Correction should be carried out of factors contributing to unsafe acts, such as fatigue, unsanitary conditions, morale, esprit de corps, or insufficient or too glary lighting Prework medical examinations are essential Repeaters and those constitutionally unfit should be placed in safer jobs Error in carrying out the above is classed as "man failure" and is up to the management.

Guarding machinery has been classed by Heinrich as follows

A. Designing and constructing tools so that guards are not required
B Providing enclosures, covers and barricades
C Providing mechanical feeding devices
D Providing devices that prevent or interrupt the movement of tools when operators hands are in the danger zone
E. Providing remote-control operating mechanisms
F Providing mechanical devices that remove the hands from the danger zone

For item A machines are built with their working parts inside them

The guards in item B prevent the serious types of accidents and are better if factory made, integral with the machine, than if added later, and should cover all moving parts and the point of operation.

Concerning item C, hands are mostly injured at the point of operation as by saws, presses, and many others known and listed, as they placed the piece to be acted on. Mechanical feeders and removers eliminate this hazard.

Under item D are devices touched off by levers, restraining cords to wrist or the electric eye, which stop the machinery on encroachment of hands

Under item F are cords which pull on the wrists, levers that throw the hands aside, or that intervene between them and the work.

To keep hands out of danger some machines are made with a two-hand control

Signs should be conspicuous wherever there is danger

A plan to show better the three dimensions of machine parts is to color their sides differently

Hands are protected from rough or sharp objects by special gloves, but gloves should never be worn around moving machinery as they catch and draw in For workers with hot metals or glass there are gloves of asbestos which are heat insulated Some gloves have arm-protecting extensions. Some have steel ribbons or metal studs to take the wear, but such should never be worn about electricity There are exceedingly heavy, riveted gloves for handling barbed wire and gloves with palm or finger pads. Packing houses have adopted a gauntlet of chain mesh for meat cutters, which effectively prevents knife cuts. Gloves cannot act as armor to protect against blows, as hands must be movable.

Rubber gloves, protected by leather, are worn around electricity and must be regularly inspected for holes. Hands in chemicals and corrosives require special glove protection of acid resisting material, rub-

ber, rubberized fabric, or neoprene Some dermatitis-producing chemicals so soak a glove and get beneath it that better results are obtained from frequent changes of cot ton gloves. There are many protective creams to rub on the hands before work, some to keep chemicals from working into the skin and others to form a mechanical protective coating Incidence of infection can be lessened by having the hands clean, and also by periodic sterilization of liquids frequently reused, such as oil and emery in valve grinding

System of First Aid A system of first aid should be established in every plant. On the grounds should be a nurse or trained first aid man or foreman, with the necessary equipment. They dress trivial wounds and know which are potentially dangerous or in need of treatment by a doctor Every trivial wound should be reported, as these when neglected cause the bad infections Infection is usually avoided in the more serious wounds as they receive prompt medical attention. Records should be made of all, for use in eliminating the cause. The first surgical treatment by the doctor determines the future course and outcome of the wound. Here, the extra care, time, and skill used are amply com pensated for by the saving of months of dressings and by curing the patient. This first treatment should be rendered promptly and with adequate hospital facilities

CARE OF INJURED

Insurance companies have found that the best medical treatment proves to be the cheapest in the end Cut rate and farmed out, consigned medical treatment results in great expense from long period of compen sation and high permanent disability rating, and also often leaves the patient crippled Liberality in the use of x ray laboratory, and surgical attention is a small item com pared to the expense of cheap work. Com pensation and medical expense are in in verse ratio, the medical being the smaller of the two, so the higher the quality of medical treatment, the more of premiums is left for the carrier Unfortunately for the insurance company, in outside risks the patient has usually already been operated on by the time the company is notified, and it is this first operation that determines the fate With present-day speed of transpor tation it pays to take the serious cases promptly—that is, within six hours if possible—to where proper surgical treatment is available.

Surgical Reconstruction of Disabled A man with a crippled hand may be paid off for his lack of earning ability, but he faces going through the remainder of his life with a handicap It is to his benefit to be turned out with the best hand that can be obtained. This also helps society, in preventing him from being a charge on charity Is it not better to use some of the community's money in surgical reconstruc tion, to make him self-supporting, than to spend much more of it by keeping him on charity for life?

In compensation insurance, regarding reconstruction, various factors play a part. The insurance company, from altruism, may wish the man the best and reconstruct him for work. This is especially so with nonprofit state funds. A factor of discouragement, however, is that in such past cases an unreasonably high permanent disability rating may have been granted to the injured. The man is well satisfied with his result, but when coming up for a rating exaggerates his disability Also, if the man receives an excessively high rating the in surance company may be actually penalized for surgically reconstructing him. Fair ratings encourage reconstruction. Even at that, however, if a useless hand can be made useful it is worth while.

Of the many thousands of crippled hands from the war it was incumbent upon us to restore to them, by surgery and trainin as much function as possible. Some w

returned to the fighting forces and some entered industry, relieving other men for the front. By surgery we should raise our cripples to be self-supporting, converting them from being a burden on society to useful members and a help to themselves and families.

The Doctor and Workmen's Compensation. It is the doctor's duty to restore the injured by treatment, get him back to work, keep records on the case furnish reports, and render in the final report an unbiased appraisal of the function of the injured part. Reports should be complete and accurate. The insurance company wishes to know of the exact injury, the names of people present, the past history, any other disability or conditions from previous injury or disease, an appraisal of the duration of disability and of the prognosis, so as to set up for the case a reserve, whether or not the accident caused the injury, and if there is any other contributing factor Health benefits and other insurance should be reported, as the patient may be receiving more when sick than when working The doctor sees many cases where only by being alert and suspicious will he discover some disease or other cause that underlies the disability He should prescribe light work as soon as possible, instead of physiotherapy He should not be fooled by the exaggerator or malingerer, but regard objective signs, wear and calluses of the hand size of muscles, and nutritional condition The attitude of the patient is a good guide.

Getting Back to Work. A patient on returning to work improves immediately in both morale and the use of his hand There is a natural response to use of a part which is unknown from passive therapy Some employers refuse to take back a man until he is entirely well, and insist on placing him on his regular job at the start This is unfortunate. Light work should be provided either by the employer or as, at Birmingham Accident Hospital in England by a special institution connected with the hospital For this work the man is paid. A hand long crippled will need gradual working in on easier jobs at first until its tissues are ready for regular work. At first the hand is lame, weak, and awkward. Gradually with use it becomes adapted, regaining its strength, endurance, and skill. If an employer cooperates in having the man work there will be not only a lower rating because of the ability, but the hand will be exercised. Having been rated early, a man working may be called in for rerating every six months to adjust the rating according to his improvement.

Patients are often reluctant to return to work. It may be from a fear of not being able and so losing their job or a fear that the compensation will be shut off, or that they will jeopardize their claim for disability There is tendency to exploit a disability for easy living and this may be fostered by the attitude of employer or doctor by bad suggestions and by coaching from other workmen. Private patients are a good guide as to proper time of recovery

PERMANENT DISABILITY

The disability is in the part only, all the rest of the man is intact and is able largely to compensate for the loss. If the man has it in him he overcomes a moderate loss of part and does as much work as ever so it is folly to measure too meticulously and base judgment on anatomic loss.

Aspect of Patient. Compensatory ability depends on intelligence, education, ambition, courage, character, temperament will to work, adaptability, and natural skill The man who has not exerted himself to gain these qualities may cherish and capitalize his disability until the case is settled.

Serious disability lowers the man's status If he has been a skilled worker he now must learn a new trade, with usually less remuneration. He gravitates from skilled to unskilled labor With his disability he is in danger of injury and finds that his hands lack skill and endurance.

He has difficulty in finding employment as the prework examination screens him out If *one hand* is severely crippled he still can do many forms of work as elevator operator, watchman, bookkeeper, draftsman, painter of signs and houses, and welder—especially if he has some prehensile ability left. In a report of 1914 from the Ford Motor Company it was stated that almost 2 per cent of jobs in the plant could be done by one-armed men After loss of an arm about one-third remain unemployed With two hands lost the handicap is so great that monetary help is needed The less the education, the greater is the necessity for two good hands.

Appraisal of Disability Appraisal of disability in a hand should be based on loss *of useful function* Sensation and motion are about equal in value A hand without sensation to touch, pain, and movements of muscles and joints is devoid of stereognosis, protection against injury and trophic control, and is unfit for work

Of usual function of motion there is opening for grasp by extending the thumb and fingers apart, and grasping to hold objects firmly and for prehension. This is by opposition, the fingers working against the palm or against the thenar eminence and thumb, the latter encircling, or by the fingertips pinching against the tip of the thumb Another function is that of hook action with the fingers, and another of lateral or rotary control of tools by wide surface of grasp the width of the palm. Firmness of grip depends on the number of fingers and the way they grasp, and on stabilization of the wrist in dorsiflexion For any function, the arm must be able to place and hold the hand where it can work, the hand and the arm being interdependent The hand can be considered a tool that holds other tools.

Limitation of motion expressed in percentage of degrees lost from the normal complete range of motion does not express disability fairly Digits fixed in extension may have one-fifth of their range of motion, but this is useless as they cannot oppose each other for practical grasp For fingers, the last half of range of flexion, that is from semiflexion to full flexion, is more useful than the first half, and for the thumb the midpart of its range of extension and flexion and of opposition Fingers in full extension or in strong flexion contracture, or a thumb fixed at the side of the hand, lose their value and are in the way An index or a little finger if lost gives little disability The index, however, is more independently mobile, and both index and little fingers give width of grip for leverage The long finger does the work of the index. The ring and especially the long are more valuable, the latter being the stronger and a gap being left from the loss of either A stiff finger in any position is in the way Normally the motion of the three finger joints should add to three times ninety or 270°, the middle joints flexing more and the distal less than 90° Full flexion allows a slender rod to be grasped but partial flexion only larger objects. If the proximal joints are limited, half flexion of them is the better position.

The wrist is most useful in the first 40° of dorsiflexion With the wrist dorsiflexed the digits flex best, which is useful, but with the wrist flexed they extend better Ranges of motion in the hand near the position of function have their greatest value. Measurements of joint limitation are compared with the ranges of motion in the other hand and also strength of grip with three or more trials on the dynamometer with each hand without the patient s seeing the dial

If there is solid fixation of pronation and supination, slight pronation is the optimal position (writing, typewriting bench work, etc.) but if there is motion the power to supinate is more valuable than that to pronate It means more range of this motion, as supination is the first to be lost. Pronation can be done by gravity Certain limitations of wrist motion, and pronation and supination can be overcome or compensated

for by movements of the arm and shoulder

Permanent disability rating should be based on the above practical functions, which are necessary for all the various activities of the hand Other factors to consider are strength, speed, endurance, coordination and skill, all of which depend on composite functions. It is possible to make actual tests of these, but at the present time the simpler methods are used. Pain is such an intangible, subjective factor that it is better to base ratings on objective symptoms even gripping is under control of the applicant. The nutritional factor is real, but too much attention paid to vasomotor disturbances, with repeated medical examinations and court hearings, only fixes and encourages the aberration.

Permanent Disability Rating THEORY In workmen s compensation an award for permanent disability is based on decreased earning power, and is intended to tide over in support of himself and dependents until the man has adapted himself to his new environment. It is not compensation for loss of a part, though it may be based on loss of parts.

The doctor alone has the right to describe and appraise the disability, but the law making body determines the award. The disability should be based on function, but the award on this is modified by certain social aspects.

Awards are expressed in weeks of compensation figured from the percentage of disability, each per cent corresponding to number of weeks such as two or five. The states vary greatly in awards. For total permanent disability in weeks they vary from 250 to 1 000, the latter of which is considered to be for life. In most, the limit is 500 weeks and in some there is a monetary limit from $3,000 00 to $15,000 00 They also vary in that factors other than disability are considered, such as major or minor hand age, and occupation For the first factor, 10 to 5 per cent may be allowed for a major over a minor hand down to 1 per cent for a finger Rate schedules are graded for age on the basis that from 15 to 25 years of age the boy is learning and is adaptable both physically and in learning a new trade. Below 40 the disability rate decreases with the age in years, but after that age it increases because learning a new trade or adapting oneself physically becomes more and more difficult, thus, the same disability may be rated at 5 per cent at the age of 15 and 20 per cent at 70 In this, states vary, some charting a straight instead of a curved line. Occupation corresponds to wage earning The loss of a hand makes some occupations impossible and would have little effect in others, so schedules are made listing the various occupations with each type of disability There are listed from 12,000 to 18,000 specific occupations, grouped in some schedules in nine classes and arranged in tables for each type of disability

PRESENT SYSTEM There is need for a standardized, uniform system of rating throughout all the states. No system can be exact, for there are too many factors. Any schedule is bound to be arbitrary throughout, varying in justice for the individual case, but practical and satisfactory on the average.

There have long been schedules in Europe In this country, the United States Veterans Administration has one coordinating main disabilities with each of nine grades of occupation, the rates being higher for the skilled worker Earl D McBride in Disability Evaluation, gives a complete and excellent system, as also does Henry H Kessler in his book Accidental Injuries. These cover the subject in a masterly way

Considerable in standardizing has been done by the International Association of Industrial Accident Boards and Commissions, but each state has its own system.

California has an especially fair method of rating the maximum award being 240 weeks, or 4⅔ years, though a life pension is given for those with over 70 per cent of

disability ranging from 10 to 40 per cent (1 per cent for every per cent over 60) For disability between 60 and 70 per cent four weeks is added to the maximum rating for each per cent over 60 There are listed 300 different injuries, 52 major occupational classifications, and 1,800 specific ones. Major and minor hands are considered at 61 different ages. With three tables these factors are correlated, giving the percentage of disability Due consideration is given to the functional range of motion and the various main functions of the hand By separate tables the percentage is appropriately modified by such influences as grip, pain, tenderness, etc.

Most schedules have a small list of disabilities, listing only total loss or amputation of each part of the hand The disability is given in terms of weeks or per cent. The percentage of disability is expressed either as the per cent of total body loss, this being 100 per cent, or as the per cent of total loss of the arm which in turn is rated at some percentage such as 60 of total body loss, or 100 per cent. In the latter case, if the loss of a hand is rated at 90 per cent, the percentage of such disability will be 90 per cent of 60 per cent, or 54 per cent

Partial permanent disability is figured as a percentage of that part of the hand which is partially disabled If the injuries are

NUMBER OF WEEKS FOR WHICH COMPENSATION IS PAYABLE FOR SPECIFIC INJURIES IN 47 STATES (ABRIDGED AND FIGURED FROM KESSLER, 1941 Page 47)

	Permanent Total Disability	*Arm at Shoulder*	*Hand*	*Thumb*	*Index Finger*	*Middle Finger*	*Ring Finger*	*Little Finger*
Maximum.	Life	500	333⅓	125	50	40	35	30
Minimum.	260	75	75	30	20	12	11	7
Average.	634 6	220	168	58	35	28	20	15
Average award in dollars		1 540 to 4 026	1 176 to 3 057	406 to 1 061	245 to 640	196 to 512	140 to 386	105 to 274

COMPUTED PERCENTAGES OF PERMANENT DISABILITY FOR SPECIFIED INJURIES, BASED ON SCHEDULES OF COMPENSATION WITH TOTAL BODY DISABILITY AS 100 PER CENT UNDER THE LAWS OF 28 STATES (ABRIDGED AND FIGURED FROM KESSLER, 1941 PAGE 48)

	Arm at Shoulder Per Cent	*Hand Per Cent*	*Thumb Per Cent*	*Index Finger Per Cent*	*Middle Finger Per Cent*	*Ring Finger Per Cent*	*Little Finger Per Cent*
Maximum.	100	78	19	15	10	8	5
Minimum	10	8	5	4	3	2	2
Average	49	37	13	8	6 5	5	3 5

PERMANENT PARTIAL DISABILITY SCHEDULE STATED IN PERCENTAGES OF TOTAL BODY DISABILITY AS 100 PER CENT ACCORDING TO AGES. (ABRIDGED FROM THE INTERNATIONAL ASSOCIATION OF INDUSTRIAL ACCIDENT BOARDS AND COMMISSIONS, BULLETIN OF U S. BUREAU OF LABOR STATISTICS No 359 PAGE 17)

Injury	*Index of Relativity at Age of 30 with Arm as 100 Per Cent* (Per Cent)	*Total Permanent Disability 100 Per Cent* Age 20 (Per Cent)	Age 40 (Per Cent)	Age 50 (Per Cent)	Age 70 (Per Cent)
Arm at shoulder	100	40	55	65	85
Arm at or above elbow	85	34	47	55	72
Hand at or above wrist	66⅔	26 5	36 5	43 5	56 5
Thumb	20	8	11	13	17
Index finger	10	4	5 5	6 5	8 5
Middle finger	8	3	4 5	5	7
Ring finger	6	2 5	3	4	5
Little finger	6	2 5	3	4	5

multiple the percentages are added, but they should not total more than that per centage for loss of the member Total medical benefits are limited in some states and in others are unlimited for time or amount.

Evaluation of Parts Compensation per week varies in the different states from \$3 00 to \$30 00, but averages from \$7 00 to \$18.30, according to the wage. It is figured at from 50 to 67 per cent of wages.

Disability rate for partially injured hands and digits, when the part has not been amputated, can be estimated by using the per cent for total loss of that part as a basis and figuring on a percentage of that. One should think of the lesions—whether of nerves, tendons, contractures, or joints—in terms of loss of useful main functions of the hand, as mentioned above, in preference to measurements alone, because the object is to compute the relative amount of work that can be turned out. Tables of relative evaluation of parts may be found in publications of U S Veterans' Administration, Association of Industrial Accident Boards and Commissions, of the various states, of McBride, and Kessler, and in various European publications.

WORKMEN'S COMPENSATION

Workmen's compensation is here to stay Having been tried out first in Germany in 1884, England in 1897, and all of Europe by 1910, it started in the United States in 1911, when ten states enacted compensation laws. Previously, in order to receive compensation, the injured had to sue the employer as a liability action. This was a hardship to the injured, a nuisance to the employer, and a source of much revenue to the lawyers The injured, when he won would get what the lawyers did not, and the doctors the leftovers or none.

Compensation has been a blessing to all concerned. The cost is written off just as any cost in industry The injured is cared for medically and helped out financially during his temporary disability and for his permanent disability, if any The element of blame is eliminated, the common law liability is relieved, the lawyer is removed from predatory temptations and the doctor is on a better status All states have a waiting period of three days to three weeks, usually seven to ten days, before compensation starts Compensation for temporary disability is from 50 to 67 per cent of the usual earnings up to a certain maximum wage.

Number of Weeks for Which Compensation Is Payable for Specific Injuries Averaged from 46 States the Payment per Week Being on an Average 62.2% of the Wages. (Calculated from Bulletin No 78 U S Dept of Labor Division of Labor Standards, 1946.)

Arm at Shoulder	*Hand*	*Thumb*	*First Finger*	*Second Finger*	*Third Finger*	*Little Finger*	*Leg*	*Foot*	*Sight of an Eye*	*Hearing both Ears*
235 5	173	39 5	36 6	28 6	21 3	15 5	213 9	145 8	123 2	174 6

From this the average payment for a hand in 46 states is 173 weeks Payment per week according to wage and other factors is for average minimum \$8 10 and maximum \$21.34 This places for a hand the average minimum \$1,383 03 and maximum \$3,691.82

In the table of average evaluations it would seem that an index finger should be valued at much less than a thumb

REHABILITATION

In 1919 New Jersey was the pioneer state in passing an act for rehabilitation of the injured workman, and in 1920 the Federal Vocational Rehabilitation Act was passed. This Act does not include the war disabled, but is for those of industry and otherwise The administration of the provisions of the

Act is by the Federal Board of Vocational Education The object is to return the cripple to useful occupation by matching dollar for dollar whatever each state appropriates for this purpose. Every state now has a State Board of Vocational Training

Where the workmen s compensation leaves off, the rehabilitation begins It provides surgical reconstruction, vocational education, and prostheses. The object is to restore all possible to industry, making the injured self-supporting, rather than a state charge and a drain on charity

The new recruit is first examined medically If his disability can be lessened by surgery this is done. Such rehabilitation is the cheapest and best disposition of the case. A lump-sum settlement is soon squandered If, after surgery, he is still disabled, he is examined and placed by a job analyst to determine for what vocation he is best fitted Factors weighed are education, mental test, experience, interest, and choice. Aptitude tests are given for mechanical or artistic sense, finger dexterity, etc. He is then trained at a vocational school His tuition is paid for a maximum of two years, but on an average for eight months. From 80 to 85 per cent of men are replaced in industry They work in gradually, their interest, hope, and morale improve, the work is beneficial to their hands, and they are again in competition with their fellow workers. There is a great compensatory capacity in the whole body With a little help the man with a crippled hand can again make good on his own

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PART FOUR

OTHER CONDITIONS OF THE HAND

16

Congenital Deformities

OCCURRENCE AND CLASSIFICATION

Congenital deformities are particularly prevalent in the extremities. Though seemingly occurring in limitless forms and combinations, they conform in the main to certain types of pattern. A bewildering lot of names designate the different forms, but they are meaningless etiologically, and classification of the various types of deformity is unsatisfactory Most of these deformities seem to be a part of one and the same phenomenon, occurring as they do in multiple and in different forms in the same individual, and often in different forms in succeeding generations of a hereditary line. Apparently they are closely related and not clinical entities In some families a particular type of deformity runs through many generations

Certain types are repeatedly found together such as syndactylism, polydactylism, brachydactylism or brachyphalangism, ectrodactylism, and others. Deformities of hands are often bilateral and are also found in the feet, or are associated with other deformities throughout the body In degree they vary from involvement of one or several fingers to absence of the whole limb at the glenoid, or of all four limbs. Classification is largely based on skeletal form, but defects of the soft parts accompany those of bone and there are even changes extending far centrally in the nerves of the affected regions. It is only in the mildest deformities that but one type of tissue is involved. No attempt at classification includes all cases. Classification is based on certain aspects only, with such arbitrary divisions as mild and severe (the latter being an accentuation of the former), hypoplastic and hyperplastic, anatomic arrangements in rays or segments of limb, or embryologically according to the times of differentiation of the deformed part. The most intriguing aspect is the etiology, and enough of this is known to at least merit discussion, especially from the standpoints of heredity, embryology, and phylogeny

ETIOLOGY

Heredity

Transmission. The hereditary tendency to transmission of congenital deformities is thoroughly established. In many instances the hereditary continuity is astonishing, but in a great many cases no deformity is known among the immediate relatives The character may be recessive and crop out in odd generations only when similar genes chance to meet. There is also the possibility that, due to some existing trend, the deformity occurs in that individual only

Almost all types are hereditary, a possible exception being megalodigity, which is a hyperplasia instead of a defect. The following deformities are reported as especially hereditary

Syndactylism, polydactylism, brachydactylism and brachyphalangism, ectrodactylism, split hand, clubhand, clinodactylism, symphalangism, lobster claw, and dyschondroplasias. Typical of the many reports on the hereditary aspects are the following

Fig. 652A. Three generations of malformed hands and feet.
Daughters mothers, and the grandmother on the right. The grandmother is V 14 in the pedigree chart Fig. 652B and the deformed daughters are VI 22 and 25 The abnormal child is VII 17 and the normal child is VII 14 The marriage of an affected individual who is heterozygous for the dominant gene would be expected to yield one normal child to one abnormal. As deformed parents thus have some normal children, they believed that the deformed children are born to them because of a lack of religious zeal. (After Hegdekatti, Malformed hands and feet, Jour Hered., 30 192–193 No 5 1939)

R. M Hegdekatti describes a closely intermarried family of a caste in India as shown in Figs 652A and B, in which 23 members have normal and 23 others deformed hands, showing the ratio to be that of a mendelian dominant All marriages were with normal individuals, outside of those affected Their deformity, with minor variations, was reduction of digits to one on each extremity

Tubby reported five generations of cleft hand

De Forest Willard reported 15 lobster claw hand children out of 22 in one family

Hall found in a family of 300, 100 with brachydactylism and brachyphalangism

Kanavel found 37 to be hereditary out of 78 of his cases

Cushing reported 25.8 of 302 members of one family to have symphalangism

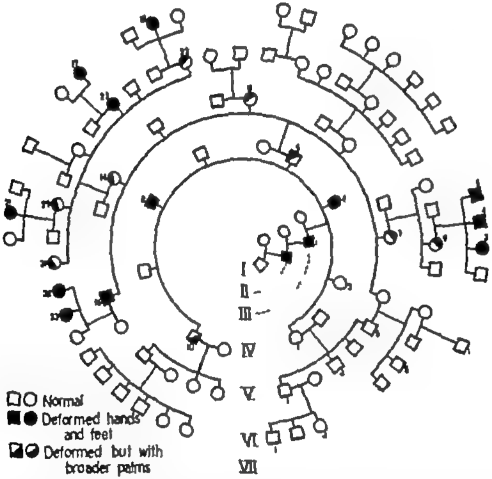


FIG. 652B Six generations of malformed hands and feet.

Pedigree chart showing the origin of the mutation from normal parents. Although in the second and third generations all offspring are affected, and in two families IV 10 and V 11 all are normal, the chance errors are balanced if we total all offspring in affected families to date which give 23 affected to 23 normal exactly what one would expect for a simple autosomal Mendelian dominant.

Hegdekatti concludes

(1) This trait of malformation of hands and feet came into existence by mutation.

(2) It is a single factor mutation which affects only hands and feet. It behaves as a single Mendelian dominant in inheritance

(3) It seems that this trait is autosomal and not sex linked

(4) There is some variation in the degree of malformation, the offspring exhibiting any degree regardless of that manifest by the parent. (After Hegdekatti Malformed hands and feet, Jour Hered., 30 192–193 No 5 1939)

Drinkwater traced short fingers through seven generations, and of these all 25 who were living had short fingers.

Other deformities have been reported through six generations (Mohr and Wreidt) and ten generations (Kellis) structive and act as a hereditary influence to check development of a part at a critical stage, the nature of the resulting deformity depending on the degree of destruction and the embryonic stage in which it occurred. They may act on a certain anatomic site,

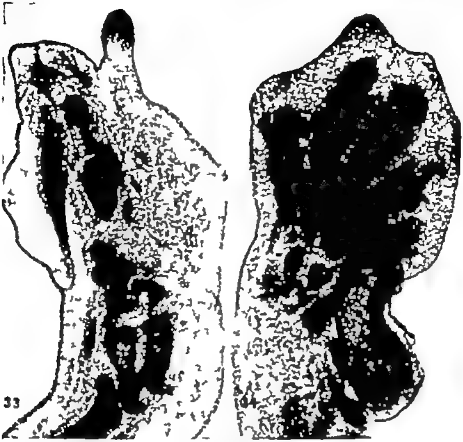


Fig. 653 (33) Microphotograph of a lateral section through the right hind foot of a 13 5 mm fetus showing the formation of a bleb on the surface of the foot. Note the escape of blood into this distended lymph space.
(34) Microphotograph of a section of a fetal foot cut parallel to the dorsum of the foot, showing a small localized blood clot in the lower right of the illustration. The fetus is about the same age as the preceding animal.
(Courtesy Bagg Halsey J Hereditary abnormalities of the limbs their origin and transmission Amer Jour Anat., 43 167–220 1929)

It is seen that a certain type of deformity may be transmitted in pure form with only slight variations through many generations, while in other families there is a predisposition to deformity in a wide range of types. In the words of Bagg "When considered as a general tendency to abnormal structure they approach mendelian expectation in behavior" The characters producing a deformity are apparently de- as hand, arm, or certain rays or selectively on a particular type of tissue, such as bone growth parts that may be distributed widely, or they may have linked with them a *syndrome of deformities*, such as with arachnodactylia.

There has been much variance of opinion in the transmission of congenital deformities as to whether the character is dominant or recessive. In some instances, as in

the family reported by Hegdekatti, it appears to be clearly dominant, and in others, like Bagg's mice, recessive There are so many instances where the behavior is atypical that there are probably varying degrees of dominance or recessiveness, so-called "qualified," that the same effects are not always produced By mutation variations are produced, and when exaggerated these are called deformities and thereafter may be transmitted as mendelian dominants.

Germ Plasm Affected by Roentgen Ray An extraordinary and enlightening series of experiments was carried out by Bagg of Cornell, who, by subjecting mice to five light roentgen exposures on successive days, produced a strain prone to have deformities of the paws He traced them through 19 generations and found the deformities to be mendelian recessive. In 5,200 of these mice he obtained 432 with defects of front or hind paws, consisting of syndactylism alone 9 cases, club and syn

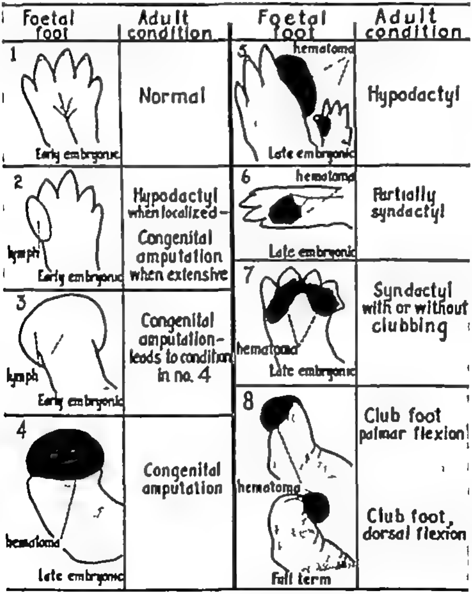


FIG 654 This chart illustrates the early and late fetal abnormalities of the limbs and the abnormal structural conditions of the limbs at birth, and indicates the probable condition of these members in later life. The adult condition is indicated to the right of the illustrated abnormality (Courtesy Bagg Halsey J Hereditary abnormalities of the limbs, their origin and transmission Amer Jour Anat., 43 190 1929)

dactylism 29, club 300, polydactylism 93, amputation 16, and hypodactylism 27

The x rays apparently affected the heredity characters of the germ plasm, resulting in arrest of development On opening the pregnant females surgically, certain lesions could be seen through the transparent membranes of the uterus that resulted in the deformities He even marked these fetuses by clipping their tails or removing all the fetuses but the deformed ones, so that the lesion seen in utero could be checked after the mice were born with the deformity produced. The usual lesions varied from a bleb in part of the paw, or a bleb with some blood clot within it, to a hematoma on the side or back of the paw A mere bleb led to a mild deformity like syndactylism, and the greater the lesion the greater was the deformity, ranging through hypodactylism, polydactylism, and clubhand. When the lesion was severe, such as a hematoma which formed a spherical mass at the end of the limb, the deformity produced was amputation. Flexion contracture was seen to result on the side of the hematoma A dorsal hemorrhage would cause syndactylism with or without clubbing (Fig 654) Strangely enough linked with these deformities were defects in eyes and kidneys. The deformities were noted in the third and subsequent generations, and following these occurred true mendelian recessives through 19 generations.

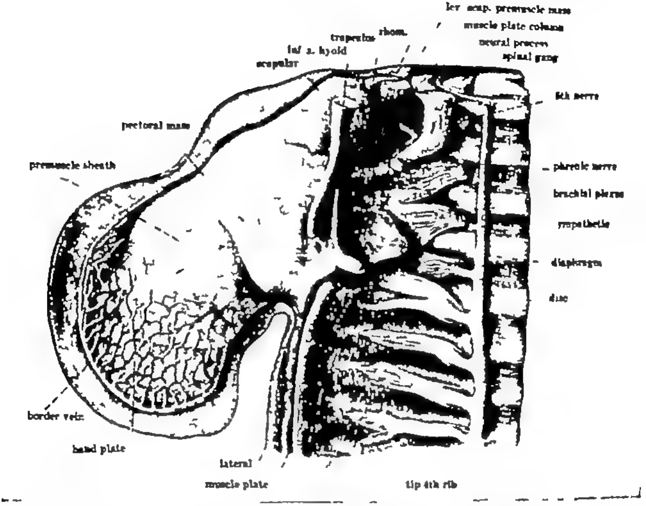


FIG. 655 Ventral view of the arm region of human embryo. Length, 9 mm. ovum size, 25 mm. dia. age, 4½ weeks. (Courtesy Lewis, Warren Harmon Amer Jour Anat., 1 157 1902)

Apparently what was inherited was that which caused the lesion, bleb hemorrhage, or destruction at the certain period of embryonic development that resulted in the deformity

Acquired characteristics of an individual are not hereditary Evidently the effect of the radiation was on the germ plasm itself

EMBRYOLOGY

Arrest or Aberration in Development. Most congenital deformities occur as an arrest or an aberration in development at some stage of embryonic life So for clarity a review of the embryology is essential Below is the embryology of the upper extremity arranged chronologically as culled largely from the monumental works of Bardeen and Lewis, and Keibel and Mall, for easy reference in ascertaining at what stage the commencement of each of the various types of deformity must have already been present

For the list of typical deformities the

CHRONOLOGIC EMBRYOLOGY OF UPPER EXTREMITY

Embryo (Age)		
2½ wks.		Along each side from the 4th to the 26th segments there arises a wolffian ridge, as in the early elasmobranch which is destined to form limbs
3 wks.	4 5 mm.	Opposite the 5 C and 1 T myotomes an arm bud arises laterally from this ridge, flat and with a cephalic and caudal border Covered with ectoderm it contains only undifferentiated mesenchyme
4 wks.	9 mm.	Differentiation starts within bud, which now inclines forward parallel to trunk From condensation of mesenchyme (no cartilage yet) can outline bones of arm and muscle groups. Nerves reach to base of arm Scapula, humerus radius and ulna show as short and thick Hand is an undifferentiated disk with marginal vessel rings which become the arches (see Fig. 501)
4½ wks.	9 mm.	Constriction for elbow separates rounded arm from flattened disk. Scapula is opposite fourth and fifth cervical myotomes
5 wks.	10 5 mm.	Arm develops Two constrictions separate to arm forearm and hand. Elbow shows slight bend. Forearm is in midposition Bones of arm, scapula humerus radius and ulna show as cartilage but not in hand. Acromion and coracoid processes and clavicle show Hand shows finger rays as rods of condensation, scallops marking ends of digits Carpal bone condensations show the scaphoid in line with the radius and lunate with the ulna Muscle groups and nerves visible premuscles showing as intrinsics
6 wks.	16 mm.	Musculature developing Individual muscles differentiating Arms show joint zones but no joint cavities Hands with slight finger projections and with dorsal grooves between digits but still webbed as mittens Cartilage shows in metacarpals (the first is half length like a phalanx) and the four ulnar proximal phalanges, but carpal bones show only as condensed mesenchyme. Os centrale shows, but in eighth week fuses to distal dorsal part of scaphoid Nerves at plexus are pulling caudally (Embryo V L III)
7 wks.	20 mm.	Fingers interdigitate and grow fast The arm now has most of its structures It projects ventrally and caudally and bends at the elbow and wrist. The radius pronates over the ulna and the palm faces the belly Vessels, nerves and muscles reach to distal parts Shoulder starts to migrate, the scapula being opposite C I and 5 T Embryo XXII
8 wks.	24 mm.	The hand is large but the arm is short. Cartilage is present throughout with the exception of the distal row of phalanges As yet there are no joint cavities. The thumb and fingers are free
3rd month	100 mm.	Osseous centers commence to form. Joint cavities begin to show The scapula has reached its final position

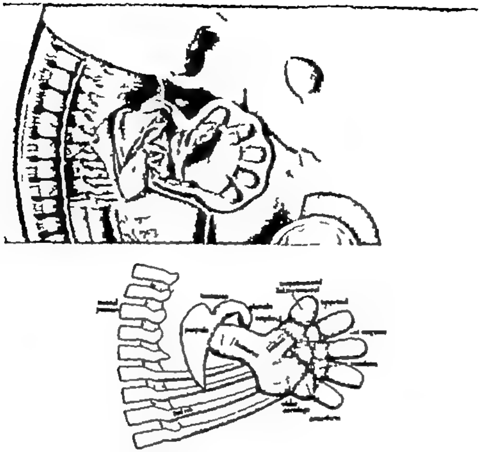


FIG. 656 (*Top*) Embryo CIX, length, 11 mm. age 5 weeks ovum 30 mm. dia. Shows beginning of hand and arm before interdigitation. Scapula is descending having started opposite the fourth and fifth myotomes. Its tip border is now at 6 C and its lower overlaps two ribs, the first three of which show (Courtesy Bardeen and Lewis Amer Jour Anat., 1 Plate IV 1901)

(*Bottom*) Diagram from same embryo showing undescended scapula and the precartilage differentiated to form the arm and hand bones. (Courtesy Lewis, Warren Harmon Amer Jour Anat., 1 161 1902)

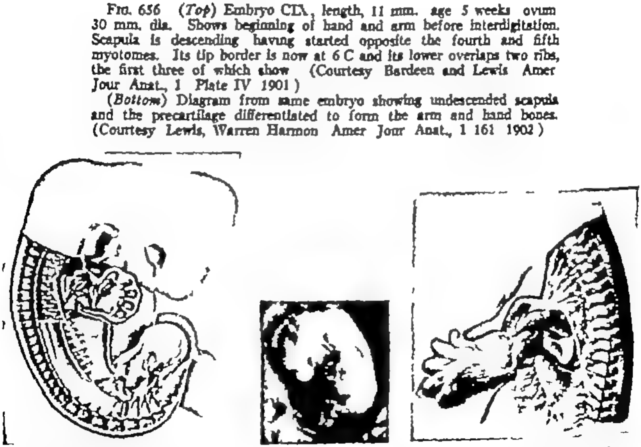


FIG. 657 (*Left*) Embryo CIX length, 11 mm. age, about 5 weeks. Hand forming within paddle.

(*Center*) Embryo CLXVII length, 14.5 mm age 5¼ weeks ovum, 33 x 30 x 20 mm. The hand is like a mitten. Scallops precede interdigitation.

(*Right*) Embryo XLIII length, 16 mm. age 6 weeks. Interdigitating (Courtesy Bardeen and Lewis Amer Jour Anat., 1 Plate I 1901)

fetal ages are given by which time the deformity must have already been determined as it could not have occurred after the certain structures involved had differentiated. (See second column.)

The particular deformity or the tendency to have some deformities is determined in the germ plasm in the gene in the chromosome. The type of deformity, unless specific, may rest on chance in that in the fetus the determining lesion marked by bleb or hemorrhage may occur in any part or at any stage of development. Thus it may be located in a certain digit or arm segment or ring, or if early it may affect the radial or ulnar ray and its branches, while if occurring late, after the arm has already been differentiated, it may affect only the joints or the parts of the digits which are still undifferentiated.

Times at which deformity is already determined

Abrachius

Phocomelus

Hemimelus

Ectrochira

Polydactylism

Lobster claw

Brachymelus

Ectrosyndactylia (defect in radial or ulnar bud)

Brachydactylia

Poikilodigiti

Syndactylism

Elevated scapula

Brachyphalangia

Symphalangism

Dyschondroplasia

TWINNING OR REDUPLICAT... MINAL PARTS

There is a widespread ... in low forms of life to grow a ... age when one is broken off ... one when partially broken. T...

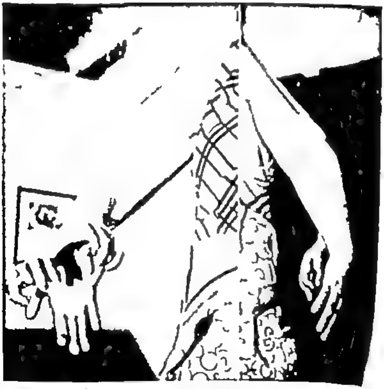


FIG. 658. Double humerus with three hands and ... teen fingers.

(*Left*) Anterior view with forearms in supination. ... common thumb for distal and middle hands, also ... mentary finger in web between middle and proximal ha...

(*Right*) Posterior view proximal and distal hands vi... (Courtesy Stein, H. C., and E. H. Bettmann, Amer. J. Surg., 50: 337, 1940.)

tacean may develop two claws or a lizard two tails. This offers an explanation of polydactylism, marginal supernumerary digits, twin thumbs, or even twin or mirror hands A small, partial congenital defect on one side in early fetal life is a plausible explanation, as concluded by Bagg After finding such lesions in polydactylism, and the association with polydactylism of club and syndactylated hands which he found to follow embryonic hemorrhagic lesions, he states 'Stochard and others have shown that a reduplication of embryonic parts may be brought about experimentally by a temporary arrest of embryonic development at a critical growth period When a growing apical bud is arrested in development by pinching off or other methods, dichotomous growth occurs, and as a result the two adjacent axillary buds quiescent during the supremacy of the apical bud begin to develop twin branches Similarly, Stochard has produced a reduplication of parts and marked degrees of twinning in trout embryo by arresting the development at a critical growth period.

Arndt and Schultz claim that minor stimuli cause irritation and result in overgrowth or division, while major stimuli cause inhibition and result in stunting webbing, absence, etc., or necrosis and loss. A remarkable case of twinning was reported by H. C Stein and E H Bettmann, which is the most bizarre case on record. The right arm of a woman 52 years of age was double in size and had three hands. There was a giant scapula, 9 x 9 inches, attached to the fourth cervical vertebra, where the spine was curved to the right there were two radiuses and three ulnas The three hands all functioned and moved independently, and there were even two rudimentary fingers of a fourth rudimentary hand located in a web between the hands. The hands were rotated 90° from each other

Atavism

Coupled with heredity and embryology both of which are fundamentals in the etiology of congenital deformities, is atavism. Atavism is but long-distance heredity, and our development phylogenetically is reenacted embryologically in each generation A search for possible atavisms should be along only our direct ancestral line from fish through a certain limited line each of amphibians, reptiles, and mammals through primates.

In the fish there is no arm but only a hand, as in the deformity of phocomelus. The arm and pectoral girdle developed later, as did also the neck. Thus the arm and shoulder are supplied by higher segments (5 C, 6 C, and 7 C) than the hand (8 C, 1 T) Phocomelus is the clinical deformity in which the arm is the defect, the hand joining directly to the trunk. In the embryo we have first a hand but no arm. Then a large hand with a short stub of an arm. As the arm and hand bones form they are short and broad as in the amphibia.

The shoulder in the embryo starts high opposite its nerve segments, but descends as in phylogeny, dragging its nerves caudalward—unless in the deformity of elevated scapula it remains in the primitive position In the fish the shoulder girdle is high and attached to the head, the omovertebral bone joining the suprascapula to the occiput. In man with Sprengel's deformity, this bone joins the scapula to the fifth cervical vertebra, as the fish had no neck The elongation of the neck is related to the descent of the scapula, and, therefore, the cervical spine is often also deformed in this condition.

It is tempting to consider polydactylism a throwback to the multirayed fin, but this is doubtful in the usual case, as it is associated with other deformities and the many rays of a fish are probably only projections

beyond the bones which evolved to the pentadactylate hand.

Man still retains a hand not far removed from the primitive amphibian type, it being much less specialized than in most vertebrates The os centrale, present in most mammals, appears in the fetus, and if it does not fuse to the scaphoid remains as the deformity of bipartite scaphoid There is reason to regard the metacarpal of the thumb with its epiphysis at the proximal end instead of distally, as in the others, as a fusion of the proximal phalanx and metacarpal This might account for the frequent deformity of the three phalangized thumb.

Aside from atavism there are typical variations repeatedly found in animals which are also seen in congenital deformities. Many reptiles have ribs to as far as the skull In man a cervical rib is a deformity Though many mammals exceed in number five lumbar vertebrae, a sixth in man is a deformity Similarly in many animals the number of digital rays may be decreased or phalanges in a digit may be increased or decreased as is the tendency in our deformities. In man it is a deformity to have a defect or synostosis in the radius or ulna, but in many animals either the radius or ulna is represented by a rudimentary remnant synostosed to the other bone. Synostosis between carpi and digital rays so prevalent normally in reptiles, birds, and mammals is typically a deformity in man These merely show that there is a natural trend in many deformities to conform with well-established natural animal modifications.

Effects of Disease or Changes in Utero

It is an old belief that some deformities are caused in utero It was supposed that insufficient amniotic fluid resulted in compression, bending the extremities clubbed, and that constricting bands of amnion, adhesion, or umbilical cord strangled limbs, resulting in the circular furrows found, and even in amputations Bagg and others have shown definitely the fallacy of these theories All limbs are curved in utero anyway, and when there has been known lack of amniotic fluid deformities have been absent. Clubfeet have been seen as early as in the third month in utero and frequently in the fourth and fifth months Against strangling by bands is the fact that these annular lesions and amputations, like clubfeet, etc, are often only a part in the same individual of multiple deformities in trunk and extremities These annular grooves which are merely a circular defect, instead of segmented or longitudinal, may be of any depth, thus occasionally resulting in actual amputations with scars terminating the stumps.

The neurogenic theory of deformities is untenable with the possible exception of hypertrophied parts of limbs, such as megalodigity which are accompanied, or possibly caused, by neurofibromata. In various congenital anomalies Moore found in seventy-eight cases that 91 per cent had neurofibromata In extreme defects in limbs changes have been found in the cord and even centrally, but were apparently just a part of the defect. Congenital do not even resemble paralytic deformities.

Acquired Deformities

Deformities can be produced in rats from insufficient diet, as shown by Josef Warkany and Rose C Nelson When fed cornmeal 76 per cent, wheat gluten 20 per cent, calcium carbonate 3 per cent, sodium chloride 1 per cent and vitamin D, many fetuses were absorbed and died, but of those that were born 295 were normal and 189 (39 05 per cent) showed various anomalies, in over half of which the skeleton was involved especially peripherally The humerus was

seldom affected, but many showed absence or shortening of radius or ulna. Half of the deformities were of hands, usually absence, shortening, or fusion of the digits or meta carpals In contrast, those fed an addi tional 2 per cent of pig's liver did not show anomalies.

Their further experiments showed that the particular ingredient of pigs' liver that was necessary to prevent abnormalities was riboflavin, the other four forms of vitamin B being ineffective. Riboflavin prevented abnormalities if given as late as the thir teenth day of gestation After the fifteenth day it was ineffective, showing that the abnormalities were determined on the thir teenth and fourteenth days, just when chon drification occurs Cartilage precedes bone.

Lack of vitamin A caused blindness (Hale and Cannon) and D curved radius, ulna, tibia fibula and angulated ribs Warkany concludes that human anomalies of forma tion are determined by the third month of pregnancy and from then on the variations are merely a matter of growth

Gregg in 1940, and verified by others, found that most women who acquire ru bella in the first two months only of preg nancy have offspring with various congeni tal anomalies, as deaf mutism cataract, heart defects hypospadias, Mongolism, mi crocephaly and feeblemindedness

Similarly Snedicor and Harryman reported on the Jackson White family traced through four generations for 150 years, isolated people in the Ramapo Mountains, in which half the progeny had syndactylism and polydactylism occurring in 50 per cent of the second and third generations and in seven out of nine in the fourth though each mating was with a normal. These people started from female derelicts from the streets of London, brought here for Hessian soldiers The authors ascribed the deformi ties to inbreeding, low intelligence, dietary deficiencies and poverty

Additional knowledge of acquired de formities is from Charles R Stochard of Cornell, who found that all of the types of deformities described, especially of double and cyclopean monsters, could be produced in eggs of fish amphibians, and birds by slowing or interrupting the development in the early stages by low temperature or de ficiency of oxygen (factors not controllable in mammals) The kind of deformity depended not on what slowed the development, but at what stage of development it was applied Once slowed, certain parts would fail to develop, resulting in deformi ties, the same treatment causing each dif ferent type of deformity depending only on when applied In early cleavage stages, twins or doubles were produced, later eye defects and cyclopia, later brain or branchial defects, and later visceral. When one of a double was underdeveloped, it showed as from arrest of development the usual individual deformities. Whether inherited or produced by diet in mammals or by temperature and oxidation deficiencies in eggs, the deformities were of the same types.

PATTERNS OF DEFORMITIES

Deformities, being mostly from a defect or an arrest in development, are usually aplastic or hypoplastic, but some, such as polydactyly, megalodigity or arachnodactyly are hyperplastic. In the main they con form to patterns, and may be multiple and in various forms in the same or other limbs or in other parts of the body, as if each is part of the same process.

The same type of deformity varies in severity in different individuals, such a series in order of increasing severity being syndactylism, brachyphalangism, brachy dactylism, ectrodactylism of the thumb and index finger, absence of the radius in addi tion to the last, and finally absence of the whole extremity The defects are usually of the terminal parts but may be in any location of the limb though the latter are usually accompanied by terminal deformi

ties. Most deformities of bones start in the cartilaginous stage or earlier

A defect may be segmental, longitudinal, or annular Examples of the first are ankylosis between phalanges, absence of some phalanges, absence of the forearm, the hand terminating the upper arm, ankylosis or dislocation at the elbow, or absence of the whole arm with hand or digit springing from the trunk A longitudinal defect is usually of either the radial or ulnar bud, and this frequently includes the digits that terminate these rays. If of lesser degree there may be loss of the ulnar or radial digits alone, or instead the defect may be of the medial digits and carpal bones Annular defects range from shallow grooves to amputations.

In deformities the part may be too large or too small, too long or too short, too many or too few, or a combination There may be axial deviation from loss of a supporting bone, from a defect of soft parts on one side, from the joint being aberrant, or from the defect being in one side of the parts for bone growth

To summarize, causes of congenital deformities in addition to heredity and atavism are effects of radiation on germ plasm, deficiency diet, especially of riboflavin, low temperature and oxygenation in lower forms of life, and infection such as rubella The vulnerable period is the first two months of pregnancy

NOMENCLATURE AND DEFINITIONS

An abundance of terms have been traditionally used to designate the deformities

DEFORMITIES OF ARM

Melomelus (limb limb)	Both normal and rudimentary supernumerary limbs
Peromelus (maimed)	Deformed limbs
Ectromelus (abortive)	Monster with defective or no limbs
Hemimelus.	Distal half or forearm and hand missing
Brachymelus (short)	Short limb
Micromelus	Diminished size of limb
Phocomelus (seal)	Fetus with hands and feet, but no arms or legs
Abrachius	Without arms
Amelus.	Without limbs
Cubitus valgus and varus	Angulation at elbow

DEFORMITIES OF HAND

Clubhand	Radial or ulnar deviation
Perochirus (maimed)	Deformed hands
Lobster claw	Absence of medial part of hand
Ectrochiria (abortion)	Absence of hand

DEFORMITIES OF FINGERS (Various suffixes are used i.e., ism, ia, ly)

Syndactylism (together)	Having united or webbed digits
Brachydactylia (short)	Abnormal shortness of digits
Brachyphalangia (short)	Short fingers or phalanges
Ectrodactylia (abortion)	Congenital absence of digits
Ectrosyndactyly (abortion together)	Some digits missing and remaining coherent
Symphysodactylia (growing together)	Union of fingers and toes
Symphalangism (together)	Ankylosis usually of middle joints
Perodactylus (maimed)	Deformity or absence of one or more digits
Clinodactyly (bent)	Permanent bending or deflection of the fingers
Comptodactylism (count)	Abnormal number of digits
Polydactylism.	More than five digits
Arachnodactyly (spider)	Digits with abnormally long phalanges
Megalodactylia	Giant digits
Poikilodigiti (varied)	Varied forms of digits
Adactylism.	Absence of fingers

OTHER DEFORMITIES

Arthrogryposis (joint, curved)	Persistent flexure or contracture of a joint
Ectrogeny	Absence or defect of a part
Synostosis	Lateral fusion of bones
Dyschondroplasia.	*Multiple* exostosis and defect in bone growth parts

They need not be confusing as they mean little more than names.

CONGENITAL ELEVATION OF SCAPULA

Etiology This is included here because the use of the hand is dependent on the support of the arm, and because description of congenital deformities of the hand would be incomplete without including this atavism from the fish In the descent of the scapula, as reenacted in the embryo, in the fourth week the scapula shows as a condensation of mesenchyme opposite the fourth and fifth myotomes, in the fifth as cartilage opposite C 4 and C 7, in the seventh the scapula commences to migrate and is opposite C 1 and D 5, and in the third month reaches its permanent level with the upper border at T 2 Arrest of excursion before these embryonic ages results in elevated scapula (Sprengel's deformity)

Symptoms One shoulder appears higher and the scapula is felt above its normal position. Sometimes the condition is bilateral In a few the scapulae are on the same level, but due to cervical scoliosis the elevation, on the concave side, is masked Occasionally the defect is shown only in the muscles which elevate the scapula, thus resulting in a high position of the shoulder blade but often there is an abnormal vertebral attachment, there being similar to the condition in the fish, an omovertebral bone triangular in shape with its base at the upper third of the vertebral border of the scapula and its apex attached to the transverse processes of the lower three cervical vertebrae either directly or through cartilage.

The scapula itself is shorter but equally as long in the direction of its spine and tilted so its lower angle is near the spine, as in quadrupeds. The upper border and coracoid process are curved forward. Associated with this C 1 to C 7 defect are often cervical scoliosis (concavity toward the scapula), fused vertebrae and short neck, with ribs cervical, fused or absent. Wry neck is present in 10 per cent. The lower thirds of the trapezius and serratus magnus muscles may be absent, and those that raise the scapula are usually overly prominent. The limb does not work very well in its distorted position and appears awkward, but the person is, however, usually able to earn a living

Treatment. Correction is difficult and unsatisfactory For mild cases early, intermittent stretching may aid Myotomies are insufficient. Operative correction should be done early, at about the age of three. For younger patients the magnitude of the procedure is excessive. Correction later is almost impossible. At any age paralysis results if the brachial plexus is overstretched or the scapula is attached with the plexus on tension Arm action is dependent on stabilization of the scapula and this depends on muscle balance, the clavicle being the only attachment of the extremity to the trunk.

The operation used is that of Schrock. Through a curved dorsal incision greater than the length of the scapula and with its convexity toward the spine, the scapula is stripped subperiosteally from its muscle attachments, displaced downward, attached by suture to the ribs, and allowed to reacquire at a different level its muscle attachments. Enough muscles to free the scapula are stripped and may include trapezius levator anguli scapulae, rhomboids supra and infraspinatus, teres major and minor, serratus anticus and subscapularis.

FIG. 659 (*Left*) Congenital absence of radius.
(*Center*) Same after Albee type of operation by S L. Haas.
(*Right*) Lateral view (Courtesy S L. Haas.)

The subscapular nerve should be spared. It may be necessary to cut off the superior border or the spine, or even the acromion of the scapula. Some degree of improvement in appearance and function can be expected.

Klippel Feil Syndrome In this strange syndrome, a part of which is congenital elevation of the scapulae, is webbing of skin between head and shoulders and beneath the arms There may also be cervical ribs, large transverse vertebral processes and feeblemindedness.

DEFECT OF RADIUS

Occurrence. Congenital absence of part or all of the radius is not uncommon and considerably more frequent than of the ulna. It is often hereditary and associated with other deformities Of the 253 cases collected by Kato most showed total absence of the radius, there being 46 per cent bilateral and 38 8 per cent unilateral. Of partial absence of the radius .8 per cent were bilateral and 11 1 per cent unilateral. Any part of the radius may be absent, the shaft or either end, the retention of a rudimentary upper end being more frequent.

Defect in Radial Bud. The defect is of the radial bud and, therefore, often includes the carpal and digital rays of the radius and the radial part of the end of the humerus, or the arrangement may be segmental of C 5 and C 6, there being also a defect in deltoid upper pectoral and flexor muscles of the elbow If the upper end of the radius is present there may be ankylosis with the humerus or radio-ulnar synostosis. The radial bones of the carpus may be absent or fused The thumb is usually absent, and often the thumb and adjoining finger or two together with their metacarpals. O Rahilly in a compilation of forty cases in which the distal part of the radius was

FIG. 660 Congenital absence of ulna and the ulnar two digital rays. The elbow is flail as the radius, which is dislocated, makes a poor articulation. The two fingers are webbed. When older the radius should be arthrodesed to the humerus and straightened by osteotomy

absent, having found that in most there was absence of scaphoid, trapezium, first metacarpal and phalanges of the thumb, concludes that these bones constitute the radial ray

The defect may also include soft parts along the radial side such as muscles tendons and the radial artery or nerve from the elbow distally. These may be absent, atrophic, distorted or cicatricial the latter increasing the deformity from lack of growth. In case of absence of soft parts and presence of bone the deformity will be less.

The ulna is short, thick, and curved radially. Rarely it has been double. As it grows the hand, without its major or radial support, deviates radiopalmarward until it is at a right angle with the arm and the ulna articulates on the side of the carpus. The distortion may be so great that the radial border of the hand lies against the forearm. The fingers are flexed and, from muscle atrophy, disuse and loss of mechanics, are limited in voluntary and passive motion

Treatment. Operation should be postponed until after the second year, as the bones have not yet developed sufficiently and the hand and arm are too small. Meanwhile, using a molded leather right angle brace from axilla to hand one should endeavor to lessen the deformity and counteract that which accompanies growth. In mild cases, correction by manipulation without force may be maintained by an adjustable brace or repeated applications of plaster casts

Having lessened the deformity by splinting and traction, operation is directed first toward the soft parts. By tenotomies, fasciotomy or excision of the contracted parts the hand is made to assume the correct position freely and without strain. It is important to preserve the tendons to the thumb and index finger, lengthening them sufficiently instead of severing them. It may, in order to bring the hand into alignment, be necessary to resect part of the carpus or shorten the ulna. As a movable wrist cannot be expected, the hand should be placed in the line of the forearm and there ankylosed with good contact, broadly and massively. A year later by osteotomy of the curved ulna and by again, if necessary, lengthening tendons, the forearm is straightened

Various methods of obtaining this firm support, in joining the hand to the ulna, have been used, the most popular being that of Albee. From the tibia a rod of bone is cut. Each end is wedged, one of which is

imbedded in a notch in the ulna and the other into the scaphoid side of the carpus, to form with the ulna a Y support for the hand.

Bardenheuer also made a Y support of the carpus by splitting up the ulna a few inches and spreading it out Steindler made a double osteotomy to the lower end of the ulna, removing the segment between The lower osteotomy was made so oblique that on contacting it with the upper the hand came straight.

Sayre shortened and sharpened the lower end of the ulna, removed the capitate and hamate and thrust the ulna not only through the carpus but to between the metacarpals, as fastening it to the carpals alone is hardly sufficient.

The operations are followed by long splinting, leaving the fingers and thumb free so that function will stimulate massive bone growth.

FIG 661 Congenitally short ulna with bending of end of radius probably from lack of support.

DEFECT OF ULNA

Description Defect of the ulnar bud of the arm, though much less frequent than of the radial bud, occurs as a close complement to the latter, the accompanying defect being along the ulnar side of the arm or of the C 8 and T 1 segments and involving the ulnar digital rays. Like radial defect it is often hereditary, accompanied by other deformities and bilateral in almost half of the cases.

Hand defects are usual. The ulnar side of the carpus may be absent or fused, and as the ulna supports more rays more digits may be absent than with radial defect. These are frequently the third, fourth, and fifth, though sometimes including the second and rarely of the fifth alone, but not of the thumb

The defect is usually of the whole ulna, but may be of the shaft or either end, though of these—like in the radius—it is usually the distal portion that is missing At the elbow where the ulna should furnish joint stability the *unstable radial head* in most cases dislocates upward, the bone even crossing the humerus In some, the radius is fused with the humerus The trochlea is often missing and if the upper end of the ulna is present it may be fused with it or there may be radio-ulnar synostosis. The arm is short and the radius curved ulnarward.

At the wrist it is the *radius that gives* stable support to the carpus, so in defect of the ulna the deformity of ulnar palmar deviation is much less marked than is the radial palmar deflection from defect of the radius. It is only occasionally that the clubhand deflection from ulnar defect reaches to a right angle. Therefore, there is usually such good function of the hand, even without operation, that the member is quite useful In fact, the greater disability may be in the elbow

Treatment. As in radial defect, early splinting and manipulation should keep the

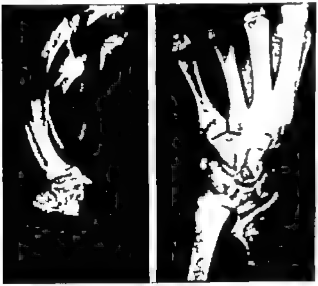


Fig. 662 Madelung's deformity (*Top*) Comparison of two wrists. (*Bottom*) X-ray appearance (Courtesy Robert Newell Stanford University School of Medicine.)

deformity in check for the first three years of growth Surgery may not be necessary but if needed is similar to that used for radial defect first correcting the soft part factor of the deformity and then stabilizing the wrist by the methods mentioned. It is the radial epiphysis from which the growth of the forearm must come, so this

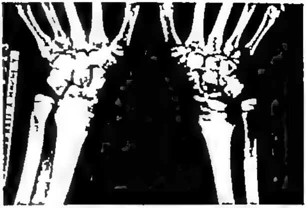


Fig. 663 Madelung's deformity bilateral.

should be preserved, if possible, using only an Albee bone graft from the shaft to support the carpus from the side At the elbow ankylosis may be necessary

Rarely both radius and ulna may be missing, the carpus articulating with the humerus, or the humerus itself may be missing, the forearm or hand springing from the trunk. More frequently one or both clavicles are absent, or the defect may be of either end or of the shaft. There is no disability, but instead greater freedom of motion.

MADELUNG'S DEFORMITY

Description This entity, though first mentioned by Dupuytren in 1839, was described more completely in 1878 by Madelung The deformity is from an epiphyseal growth defect in the lower end of the radius that does not make its presence known until the ages of 10 and 15, with 12 as the average. It is bilateral in two-thirds of the cases and four times as frequent in girls. In at least 10 per cent it is hereditary

From a lessening and aberration of growth of the radial epiphysis, the lower end of the radius curves volar and ulnar ward and falls behind in growth compared with the ulna Both radius and ulna are enlarged at their lower ends, and the relative increase of growth of the ulna makes this bone luxate from the radius and cuneiform project dorsally and distally and form a new facet on the side of the carpus. Epi

FIG 664 Case C S., age 17 Congenital clinarthrosis of proximal finger joints with Madelung's deformity and synostosis of upper radio-ulnar joint. Feet showed poly and syndactylism.

(A, *Left top*) Right hand preoperatively

(B, *Left bottom* and C, *Right top*) Roentgenogram showing clinarthrosis, Madelung's deformity and synarthrosis of upper radio-ulnar joint.

(D *Right, center*) Roentgenogram 75 days postoperatively shows clinarthrosis corrected by wedge osteotomies secured by wires. Head of ulna has been removed together with head of radius to allow pronation and supination. All flexor tendons were lengthened and a plastic zig zag was done to let out the ulnar border of the skin.

(E, *Right bottom*) Postoperative appearance. Function much improved.

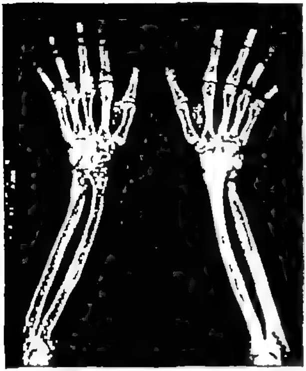


FIG 665 Regeneration of ulna four months after Darrach operation for Madelung's deformity (Courtesy Hucherson, D C Amer Jour Surg., 53 240 August, 1941)

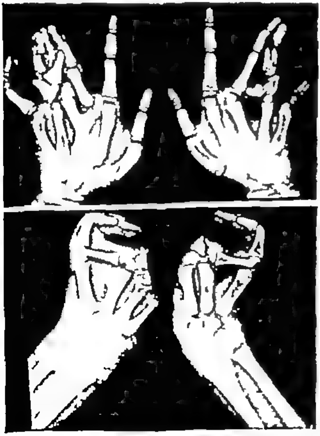


FIG. 666 Bizarre types of bilateral clinodactyly and ectrosyndactyly
(*Top*) Symphysodactylia is prominent.
(*Bottom*) Ectrodactyly predominates.
(Courtesy S L. Haas, Shriners Hospital.)

physeal damage by injury, infection, and rickets may imitate the condition, and in a few the curve has been dorsal.

Madelung's deformity has the appearance of a forward dislocation of the wrist, as there is a bayonet-like jog The anteroposterior thickness at the wrist is increased. There is pain and muscle cramping, until the deformity is established, and then a feeling of weakness or looseness. Due to the changed mechanics dorsiflexion, abduction, and supination at the wrist are limited, and flexion increased.

Treatment. Early efforts, by wearing a leather brace or applying a series of plaster casts from the metacarpal heads to well up the forearm, will lessen pain and deformity Operation is preferably deferred to obtain greater bone growth if fusion is contemplated. Otherwise a wedge osteotomy of the radius is done. First, the fibrous contractures are separated and the ulna is shortened by removing its lower end. A tendinous sling placed about it and the flexor ulnaris tendon will check backward dislocation. The forearm is splinted in slightly the opposite deformity The head of the ulna may be removed including its periosteum but within the ligments (Darrach), leaving them and the styloid process to re-form enough for radio-ulnar stability

CLINARTHROSIS OR DEVIATION IN ALIGNMENT OF JOINTS

Description. Bagg showed that an embryonic lesion on one side of a limb leads to contracture toward that side, due to a defect in development. Bones, muscles, nerves, and vessels may be absent in the concave side. At the elbow, cubitus varus or valgus are sometimes seen, due to laxity of the ligaments. At the wrist, clubhand is frequent and is usually associated with defect in radius or ulna though it does occur when the bones are normal. The deviation, usually radial or ulnarward, may be volar or dorsal or in combination, and is frequently bilateral.

FIG. 667 Microdactyly of thumbs.
(*Top*) Microclinodactyly
(*Bottom*) Aberrant thumb with defective first digital ray and absence of thenar eminence

Fingers often show flexion contracture or lateral deviation. In the former the little finger is the most involved, then the ring, but any may be affected It is usual for the middle joint to be in flexion, while the proximal and distal are in extension, though the whole finger may be in flexion. The little finger may overlap the ring Lateral deviation of the fingers occurs when one phalanx, such as the middle, is rudimentary and wedge-shaped. Sometimes all fingers and toes show lateral ulnar deviation in their proximal joints.

Treatment. In all joint deviations conservative treatment is used first, starting early in life, manipulating and then gradually stretching the soft parts by splints or casts and holding them so until the limbs grow straighter Plastic surgery is deferred until six years or more, and consists of freeing or severing the contracted parts and straightening curved bones by wedge osteotomy In clubhand the bones are treated as for defect of radius and ulna. The surgical treatment for congenital flexion of a finger is disappointing All the tissues share in the contracture, tending to reproduce it When lateral deviation in a finger is due to a rudimentary wedge-shaped phalanx, the latter may be resected and the capsule of the new joint reconstructed When all fingers deviate ulnarwards at their proximal joints, wedge osteotomies can be done through the metacarpal necks proximal to

FIG. 668 Congenital flexion contracture of all middle finger joints. For correction spring splinting is better than surgery (Courtesy of Jack Penn.)

Fig. 669 Congenital flexion contracture of each little finger

the epiphyseal lines and the bones pinned straight with Kirschner wires

CONGENITAL DISLOCATIONS

Any joint from shoulder to digit may be dislocated. Rarely, the head of the humerus may be beneath the spine of the scapula. Complete elbow dislocations are rare, though the radius is often dislocated upward, in front, at the side or behind the elbow often bilaterally and in association with defect of ulna. A few cases are reported of bilateral dislocation of the wrist, though there are many such associated with a defect of the radius. Dislocations of thumb and finger joints are usually just a part of other deformities.

SYNOSTOSES

Description. Fusion of the elbow, though unusual, may be of all bones or of humerus, with the radius or with the ulna, either at a right angle or in extension Radio-ulnar fusion is common and in some

Fig. 670 Defect in fifth digital ray synostosis metacarpal and clinodactyly

is hereditary, and in half the cases bilateral The upper ends are fused far more frequently than the lower, and in only one in *fifty* are both ends fused. The head of the radius may be luxated, giving cubitus valgus, or may be in place, and pronatory movements are frozen in the mid or fetal position. Occasionally the fusion is with *a wide angle between radius and ulna.*

Carpal fusions are fairly numerous, the usual ones being between the lunate and scaphoid, the lunate, triquetrum, and hamate, the capitate and multangular, and the carpus and metacarpus.

Metacarpals may be fused or show fusion at one end and a Y separation at the other Synostoses are frequent in syndactylism and polydactylism.

Treatment. Operative separation of the forearm bones at the elbow is often disappointing requiring multiple procedures just as in arthroplasties in children, because at that age there is such proliferative growth. The marked tendency to refuse in synostosis is just the opposite of the condition in congenital fracture of the tibia.

For synostosis of the elbow in extension, wedge osteotomy to a 70° angle will allow the arm to function and develop until successful *arthroplasty* can be done at adult age. The osteotomy, however, should be

FIG 671 Congenital synostosis in carpus (*Left*) Capitate and lesser multangular are as one (*Right*) Synostosis of radius, lunate and navicular and also capitate and hamate

done above the epiphyseal plate for later correction, lest growth be prevented

In synostoses of upper end of radius and ulna there is often also defect of muscles of supination. A wide resection of the head of the radius and the interosseus ridges for the distance of the fusion, followed by throwing in between of soft parts, is necessary to give pronation and supination, but often fails One may free the radius of muscles and allow them to reattach in the position of supination or do a rotary osteotomy of the radius to the position of supination Because of the poor late results it is simpler merely to sever the radius below the synostosis, interpose soft parts, and put up the arm in supination.

CLEFT, LOBSTER CLAW, AND MIRROR HANDS

Description Split hands and feet are often hereditary and bilateral. Tubby traced them through five generations, and Lewis and Embleton found that all but 13 cases out of 130 that they collected were hereditary Cloven front feet are among

FIG 672 Congenital fusion of carpus and four metacarpals in one wrist and capitate and hamate in the other Some complaint of pain, but wrist motion almost complete. (Courtesy of D D Butterworth and W E Daner)

FIG. 673 Case M. P G
(*Left*) Lobster claw hand from defect in middle rays. Spread between little finger and thumb only ⅝ inch.
(*Center*) X-ray view
(*Right*) Condition after operation. The web was corrected by a zigzag plastic and central cross bones were removed.

FIG. 674A. Girl, age 6 with mirror hands though radial two digits of each of the mirror hands is missing The father of this girl and his sister have similar hands.

the natural variations in animals such as ungulates or the African chameleon The hand of man functionally has two parts, as outlined by the two distal palmar creases —the proximal one for the radial three fin gers grasping against the thumb, and the distal one for the ulnar three grasping against the palm The two nerve supplies divide the hand in a line down the center of the ring finger, while the divisions be tween the two fascial spaces and the func tions of the intrinsic muscles divide it along the third ray With the radial bud are in cluded the thumb and index finger, and with the ulna the index and the other fingers The deformity of bifurcated hand may fol low these natural types of division, there being a central defect of one or more rays from the second to the third

Lobster claw hand, having only a thumb and little finger, is from a central defect of the intervening fingers Their metacarpals

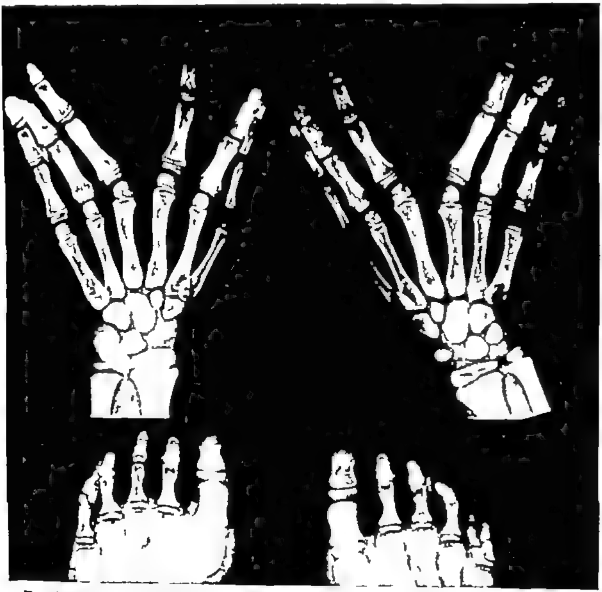


FIG. 674B X-ray films of hands. Feet show the same twinning phenomenon in the little toes. It seems advisable to excise the outer of one little toe and to select the middle radial digit in each hand to be the thumb in order to give a wide cleft between thumb and hand. The remaining two digits on the radial side should be excised, but their extensor and flexor tendons should be preserved to furnish opposition and extra strength to the selected thumb The growth of the latter should be checked by curetting the epiphyseal plates adjoining the carpometacarpal joints and filling the spaces in with cancellous bone. With surplus tendons pulley transfers may be made to give opposition to the selected thumbs.

FIG. 675 Lobster claw hand. All central digits are missing.

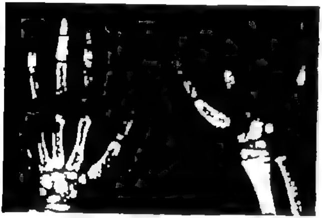


FIG. 676 Defect in central rays. Almost a lobster claw hand.

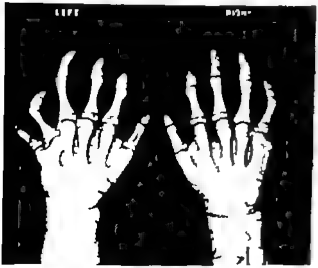


FIG. 677 Polydactyly with synostosis of metacarpals and brachyphalangia of supernumerary digit (Courtesy Robert Newell, Stanford University School of Medicine.)

FIG. 678. Polydactyly The supernumerary digit is on the outer side of the hand and with clinodactyly

A

B

C D

FIG. 679 Case D O

(A) Polydactylism of all four extremities. Instead of a thumb there are, as often happens two fingers, each with three phalanges.

(B) Feet of same patient.

(C) Supernumerary digits have been removed.

(D) Grasping ability of thumbs.

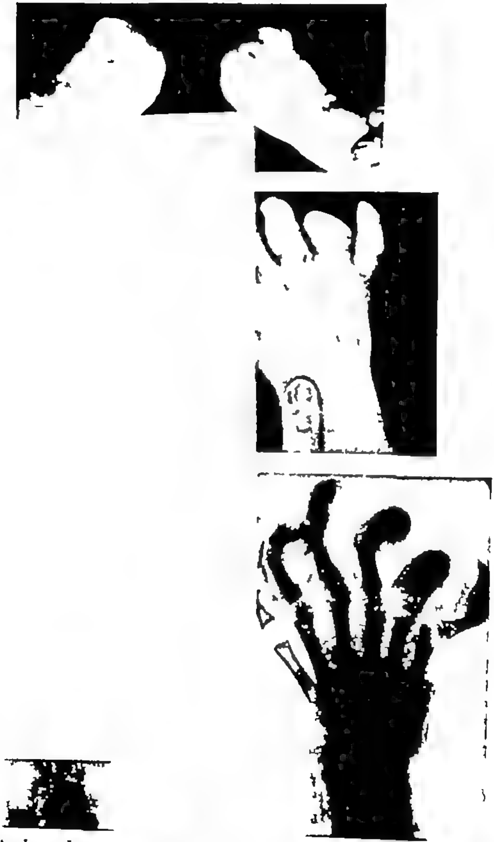


FIG. 680 Bilateral complete syndactylism of all fingers also present in mother and sister (*Top*) Before operation. (*Center*) After operation. Six fingers on each hand, one of which is to be sacrificed later (*Bottom*) X ray picture after operation. (Courtesy Haas, S. L. Amer Jour Surg. 50 364–365 1940.)

and even part of the carpus may be missing, or these metacarpals may be rudimentary and at odd angles.

Mirror hands are the result of twinning and are identical or nearly so, each being the mirror complement of the other. With this is a tendency for them to rotate toward each other. Even the carpus may be double. The thumbs are usually absent, the twinning being of the four or less digits supported by the ulna, though rarely the ulnar instead of the radial bud is the missing one. There may be, if the twinning is higher, absence of radius, but doubling of the ulna. Extra, aberrant fingers may be present, or the total number of digits may be ten or less. In Saviard's case there were ten digits on each of the four extremities. Bradford and Lovett saw a case with 15 fingers and 13 toes.

Fig. 681. (*Left*) Syndactylism in which the ends of the digits are grouped together but there are not clefts as in acrosyndactylism. (*Right*) X ray appearance of same.

Treatment. In cleft or lobster claw hand, the cosmetics may be improved by narrowing the cleft. This may also aid in function. The central metacarpals of the missing digits are excised, especially if they are more or less transverse, and the two parts of the hand are made to approach each other sufficiently. If the digits are not in opposition they can be made to be by osteotomy and if muscles are not present to make them work against each other this too, may be furnished by a tendon T operation (p. 500). For mirror hands, one is amputated with the exception of one digit preserved for a thumb, and the carpus of the other is made to rest centrally on the ends of the forearm bones, the tendons of the amputated hand being severed back to their bifurcation to prevent hindering attachments.

Clump or drumstick hand is the opposite of bifurcated hand and polydactylism, being an exaggeration of syndactylism. If allowed to remain, the abbreviated and bound digits will not develop. Therefore, early in life they should be separated and enough skin furnished to cover over their denuded surfaces. This is best done in stages, for the different clefts. The digits, when separated and working against each other, will develop.

POLYDACTYLISM

Description. This common deformity, like syndactylism, is frequently hereditary and accompanied by other deformities of the hand, such as syndactylism, brachydactylism, brachyphalangism, hyperphalangism, symphalangism and other aberrations. Deformities of the digits, the terminal parts of a limb, are much more common than of the limb itself and are more varied. Exces-

sive longitudinal segmentation of the hand, or polydactylism, *tends to* be marginal, either of the ulnar or radial borders, or to be centrally arranged in the hand, and consists usually of doubling of one or more The epiphysis of the thumb metacarpal, being basal, suggests that in the normal thumb either the metacarpal is absent or has fused with the proximal phalanx, taking on the proximal epiphysis of the latter A bifid

FIG. 682 Case P M. (A and B *Top*) Syndactylism, hands and feet.
(C *Bottom*) Postoperative. Each thumb was phalangized. Tunnels of acrodactylia were excised. Points of skin were sutured across the clefts and the sides were skin-grafted.

digits, making a total of six or more. It is most common of the little finger at the ulnar margin of the hand, next of the thumb, and least of the central parts either of index or of long and ring fingers. An extra digit usually, but not always, has a separate metacarpal and this may be fused to the adjoining one The extra little finger ranges from full size to rudimentary, being sometimes merely a tab of skin It may stand out at any angle, even a right angle.

The thumb, when involved, often has three phalanges instead of the customary two, and so may be confused with a finger thumb is common, the forking being at any level of phalanx, joint or metacarpal, though usually at the last joint. The fork may be as a Y of phalanx or metacarpal and at varying angles The extra thumb may be symmetrical and equal in length with the other thumb, or may come off as a rudimentary thumb at the radial side. Occasionally the thumb is triple and then the central member is the largest.

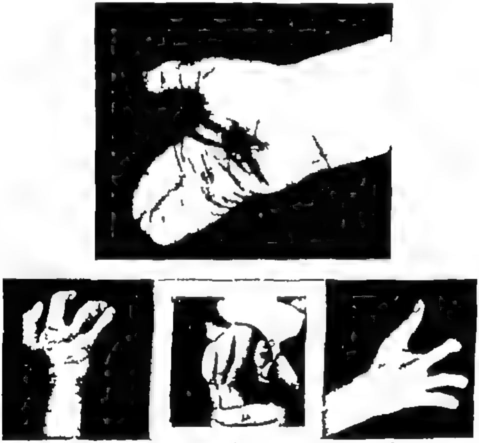
Treatment. After ascertaining by roentgen ray the condition of the bones, operation is chosen by considering both the cosmetic and functional viewpoints. In the

latter, those digits that appose each other will be the most useful One should ascertain that the digits preserved have tendons and muscle attachments, and should preserve tendons and muscles of any digit to be amputated so as to transfer them to a remaining digit if necessary In amputating median supernumerary fingers the metacarpal may need removal to narrow the hand and bring the adjoining fingers together In a bifid thumb a central wedge can be removed, so the two ends can be fused as one, or the radial member may be amputated and the other aligned by osteotomy

SYNDACTYLISM

Description This, though a mild deformity, is the commonest in the hand, occurring according to compilers once in

A



B C D

Fig. 683 Case M. W

(A) Born with a mitten. The digits were separated by John Staige Davis, who referred the case.

(B and C) Showing that there is clinarthrosis and the index and long fingers flex in planes 80 from normal. The long finger is devoid of extensor and flexor tendons.

Operation (July 28) Zigzag plastic relieved flexion contracture of long finger Nail matrices were narrowed.

A transverse rotary osteotomy on the proximal phalanx of the long finger fastened by a key bone graft from fourth metacarpal fixed the digit in the correct plane of flexion.

The fourth metacarpal of absent ring finger was removed to allow the fifth metacarpal head to snug against the third effectively correcting the rotation of the latter

(D) Condition one year later

Since then the hemi middle phalanx was removed from the index finger correcting the deviation, and extensor and flexor tendons have been supplied to the long finger

FIG. 684 Bilateral syndactylism.

every one to three thousand births Bagg found that it is from an arrest of development, starting with a fetal lesion of very minor degree. In the fetus the fingers do not grow out from their webs until the seventh week. Often hereditary and almost twice as frequent in males, syndactylism may involve any two digits or all, though rarely the thumb, and most commonly the long and ring fingers. It may be symmetrically bilateral, as in almost half the cases, and may at the same time occur in the toes. It is frequently associated with other deformities of the same hand and elsewhere in the body, and is often combined with many other types of finger aberrations The joining of the fingers may be of any degree of length or thickness of web There may be a thin web or a broad attachment of the fingers and nails, showing as a deep or shallow depression between them, or the attachment may be so intimate that the bones are fused The fusion may also involve the tendons and digital nerves, and sometimes may extend proximally to include the metacarpals and carpal bones The double nail appears broad and with a groove between its two parts Rarely only the ends of the fingers are fused together (acrosyndactylism) The joints of the adjoining fingers, if opposite each other, allow good motion, but there may be too many or too few phalanges, or a difference in finger length so the joints fail to coincide, thus preventing flexion. When only two fingers are webbed they are usually of equal length, but change to the normal length ratio after they are separated surgically Even short webs interfere with free finger

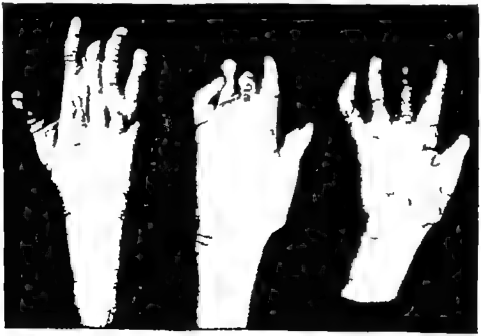


FIG 685 Age 8 years.
(*Left* and *Center*) Incompletely repaired syndactylism, done at six months.
(*Right*) Result after laying skin flaps across the clefts and split-grafting the sides of the fingers.

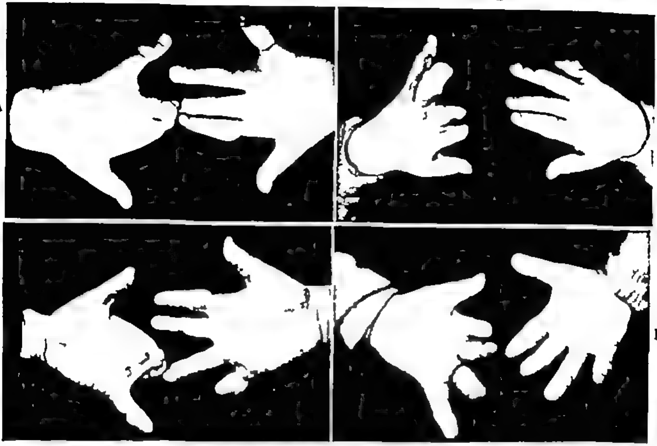


FIG. 686 Case H. L. (A and B *left*) Acrosyndactylism.
(C and D *right*) Postoperative. Right hand Annular grooves were corrected by zigzag plastics and redundant tissue was excised. Left hand Groove around little finger was corrected. Fingers were separated determining the depth of each cleft by suturing points of skin across it. Sides of fingers were skin-grafted.

movements In an adult, the length from prominence of knuckle to web is from *three-quarters to an inch. Webs exceeding* this in length show when the fingers are spread as a skin contracture across the distal end of the palm.

Each of the Dionne quintuplets, according to Scheinfeld, has the same bilateral webbing namely, between the second and third toes

Treatment. The plastic flap-swinging operations as commonly pictured, like that of Didot in which the dorsal flap is swung to one finger and the volar flap to the other finger, are failures for two reasons. Due to insufficient skin when drawn too tight necrosis or even gangrene occurs, and the scar running down one side and up the other as a V contracts as all scars do, and becomes a short U This draws down the skin of the hand reproducing the web The scar being under tension, especially as the finger grows, distorts the finger with a *lateral curvature and a rotary twist, and* draws the nail and matrix on one side back into a point. The solution to avoid this prevalent deformity is first to establish the depth of the cleft and second to furnish additional skin by partial thickness grafts. Suture lines where possible should be curved for slack, instead of straight down the finger The depth of the cleft is made fixed by first outlining a dorsal and a volar pointed skin flap The web is then slit through, and by blunt pressure the cleft is made overly deep The two flaps are then crossed through the cleft overlapping and are sutured side to side In planning these flaps we should imitate the shape of the normal web, it being in the plane of the palm and beveled to the dorsum, and we should slightly overdo the depth to allow

FIG. 687 Syndactylism. Two fingers joined are usually of equal length.

FIG. 688 Two cases of bilateral partial syndactylism on ulnar sides.

for some shrinkage. The denuded side of each finger is then covered by free skin graft. The graft should be thick enough (about two-thirds thickness) so contracture will be minimal, the actual thickness depending upon the age of the child (p 195)

An old, crude method was to establish the cleft depth with a seton. In repairing cica tricial webs, as often after burns, the tun nel graft succeeds because cicatricial flaps will not live, but for congenital webs the above double flap method is best. Quite short, broad webs can be corrected by the Pieri Z plastic.

A denuded cleft can be closed in by one piece of skin inlay graft, using a wax stent molded to the proper shape of the web and to the fingers The fallacy of this method is that each border of the cleft will contract to a short U, thus drawing down two webs, one on the dorsal and the other on the volar aspect of the cleft. This can be partially avoided by cutting a liberal, rounded redundancy projecting from each side of the graft, so there will be plenty of depth to the cleft and much slack skin on the volar and dorsal aspects The pointed flap method, however, is better

Before the skin grafts are applied the hand should be immobilized on a well padded skeleton hand splint (Fig 84) which gives free access to the clefts The fingertips are held to the splint by adhesive or a penetrating stainless steel wire. The grafts are sutured and held in place by winding the digits with ribbons of paraffin gauze. After covering with vaseline gauze, mild pressure is applied with strips of sponge rubber Excellent takes also follow direct application of a wax stent, molded and hardened before the skin graft is applied to it. One should never hold the fingers apart by wax, sponge rubber or other pads for fear of pressure necrosis. The fingers are held apart by the splint, the dressings are merely applied. Following thick skin grafts, splinting should be prolonged one to several months to avoid

FIG. 689 (*Top* and *Center*) Brachy phalangia with some syndactylism. Has had incomplete operation.
(*Bottom*) Webbing corrected surgically

tracture from irritation of early movement. Children's joints do not stiffen. On wrapping the hand and splint, both should be enclosed in a hollow plaster of Paris casing, extending up the arm and with a lid for doing dressings after the tenth day A glass slide can be set in the cast as a window for inspection of the circulation of the fingertips.

Double nails split in two by the finger separation should have a strip of their cut

FIG. 690 Bilateral syndactylism in hands, together with cleft feet

border removed, including a similar width of the matrix so the skin may be reshaped around the nail edge The same is done for nails in secondary cases, in which one corner has been drawn out to a point by the contracting scar

Complications arise in separating fingers that are broadly together, because there may be a common tendon, nerve, and vessel Joint capsules on that side may be missing, and the circulation may be jeopardized if both sides of such a digit are operated on at once. Thus in badly fused fingers, it may be necessary to operate on only one at a time If there is but one tendon it should go to the better finger, and a tendon graft placed in the other later The single nerve should go to one finger, as nerve supply in a growing child will be established in the other finger If the joints will be left without a capsule on one side it is better not to operate on the fingers, but to leave them double—especially if there is good function.

A B C

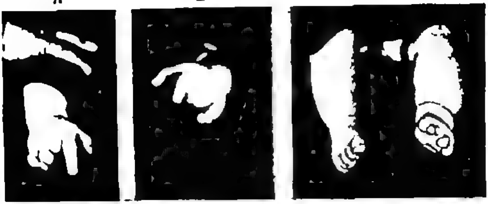


FIG. 691 Case L. H.

(A, B, and C) Bilateral acrosyndactylism, brachydactylia, and annular constriction Left long and ring fingers and right ring and little are joined at their tips. A crossbar is between the ends of two toes. Ring defects are seen in fingers of each hand and in two toes of each foot, first and third of left and second and fourth of right. Above the left ankle is another ring defect with swelling below it.

(D and E) X ray views show rudimentary and absence of the distal two phalanges in each hand.

D

E

FIG. 692 Showing the incorrect operation for webbed fingers. There is not sufficient skin and the linear scar down one finger and up the next is later drawn by contraction from a long V to a short U re producing the web and distorting the fingers in rotary and flexion contracture, as shown in the lower illustration. (Courtesy Jour Bone and Joint Surg., 14 44 1932)

The age at which to operate is important Infant fingers are short, and grow greatest in the first and early years A scar made along the side may greatly distort as the finger grows, just as after a Didot opera

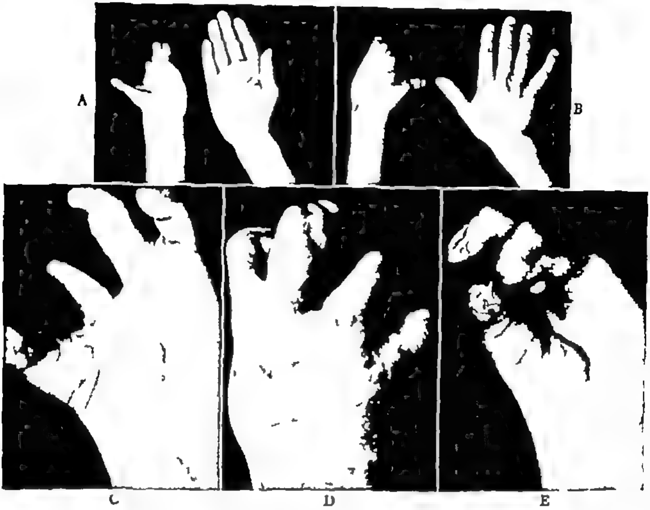


FIG. 693 Case E. S (A and B) Syndactylism and brachydactylia.
(C, D and E) Postoperative. Flexor tendons were supplied grafting from both palmaris longus tendons to each digit as all flexors terminated at the bases of the digits. A rotary angulatory osteotomy was used on the last metacarpal so that finger could work against the thumb.

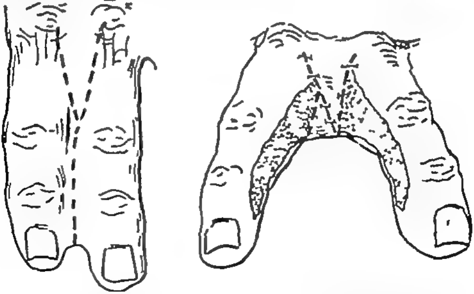


FIG. 694 Correct method of relieving a contracture between two digits or webbed fingers. The pointed skin flaps sutured across the cleft, establish the depth of the cleft. The denuded sides of the fingers are covered by free skin grafts. (Courtesy Jour Bone and Joint Surg., 14 44 1932)

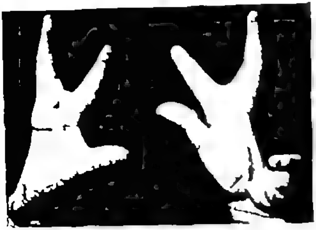


FIG. 695 Bilateral defect in one hand of the two ulnar digital rays and in the other the fourth ray The fifth shows clinodactyly and grows from the carpus. The distal two phalanges of the aberrant finger were later amputated and the base of the finger was fused with the hand to give a broader palm and some cupping ability

tion, and require one or more plastic operations later as the child grows (Fig 692) If the fingers, due to the joints not coinciding or from being held together in a group, are so that they cannot function they will not develop unless they are freed for function For these, operation should be done early, but scars should be so curved that contractures from growth will be lessened If in a case there is good function the fingers will develop normally and operation may be delayed until the age of six or more, but not too long as children acquire complexes The shorter the web and freer the motion, the better it is to wait until the fingers attain size

ECTROMELUS AND ECTRODACTYLY

Abortive development or defect may be according to rays, segmental or annular If it is a ray defect there may be absence of one or several digits, usually grouping as either of the marginal or the central portions of the hand, or with absence of the radius or ulna or their respective buds, including the digits Often the thumb and its metacarpal are missing, or similarly the little finger Absence of central rays is described under cleft hand.

When the defect is segmental, there may be absence of any or several segments in the limb Even all four limbs have been missing up to the glenoid and acetabular sockets, as reported by Price The missing segment may be only one or several in a digit, or of a digit itself, or of several digits The whole hand may be missing or represented by one or several fingers, rudimen

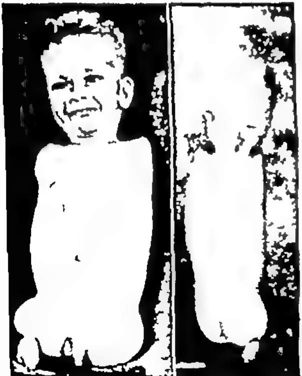


FIG. 696 The patient at the age of 3 years. Note ability to hold toys with his chin. Only 4 reported cases. One other living age 64 (Courtesy of W P Killingworth and R. Engledon Congenital absence of the four extremities, Amer Jour of Diseases of Children 63:916 May 1942)

FIG. 697 Congenital three-fingered hand.

FIG. 698. Rays on radial side underdeveloped and one missing probably in dex, the main defect being through the second ray

tary or not. If the whole arm is missing usually the hand is also, but in some the forearm is missing the hand being joined to a rudimentary humerus, or the whole arm may be missing the hand joining directly to the trunk (called phocomelus from the seal, though really the seal has an arm) In an adult case seen personally there was only one finger springing fro shoul der Absence of the arm f the

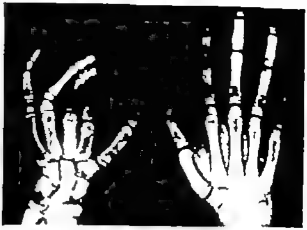


FIG. 699 Clinarthrosis and brachy dactylia. After relieving the webs the ex tensor tendon of long finger was transferred to the interosseus tendon on the ulnar side of the ring finger correcting the position of that finger

hand, corresponds to defect from C 5 to C 7, but absence of radial and ulnar aspects of the arm to that of C 5, C 6 and C 8, T 1, respectively In brachymelus the arm is merely short and in hemimelus it is miss ing from the elbow Treatment is to no avail unless it consists of merely construct ing a digital post for the thumb for the re maining fingers to work against.

BRACHYDACTYLIA

From arrest in development in the em bryonic hand, one or all digits may be short. Usually some phalanges or metacarpals are short or absent. The distribution of short hand bones may be grouped on either side or in the middle of the hand or across any row of the phalanges or of the metacarpals though most commonly the middle pha langes are involved

HYPERPHALANGISM

In contrast to brachydactylia is hyper phalangism or excessive number of pha langes, the digit being long or of normal length and the thumb being the one most commonly affected, having three instead of two phal ariation in number of phalang on in vertebrates that it can b s a frequent anomaly

FIG. 700 Defect of central digital rays The long and ring fingers are fused in one. Born with right leg absent below knee and left to above ankle.

SYMPHALANGISM

Here the defect is in the development of the finger joints, there being instead bony or fibrous fusion between the phalanges Drinkwater traced this condition through 14 generations.

ARACHNODACTYLIA

There is a strange shape of hand with long and slender fingers suggesting the legs of a spider, in which the phalanges and metacarpals are excessively long and the fingers are held in flexion as if the bones exceeded the tendons in length Other long bones in the body are also elongated and thin, and these long bones may be affected alone without elongation of hands or feet. The condition is suggestive of endocrine disturbance, such as achondroplasia or fragilitas ossium (marble bone with blue sclera)—the latter condition having several times been found in association

The spider hand is only a part of a syn drome, in which these people from laxity of ligaments are double-jointed and clumsy and the lens of the eye dislocates They are tall slender, and weak, having undevel oped musculature, and may have infanti lism congenital heart disease, scoliosis, kyphosis and pigeon breast.

ANNULAR GROOVES AND CON GENITAL AMPUTATIONS

As stated above, these are not from intra uterine bands, but are merely ring-shaped

FIG. 701 (*Top*) Brachydactylia and syndactylism.
(*Center*) X ray appearance showing only one or two phalanges to a finger
(*Bottom*) Syndactylism corrected surgically at one year so hand will develop.

FIG. 702 Brachyphalangia.

FIG. 703 Brachydactylia. Shortening of several metacarpals, of which the epiphyseal lines appear closed.

defects These ring like grooves may be shallow in the skin and subcutaneous tissues only, or may involve the deep fascia or be to any depth. They are single or multiple, and occur often in the central or lower part of the forearm and high in the upper arm They may occur in a finger or there *may be a rudiment of a finger separated* from the hand by a ring If a ring is shallow it causes edema of the part distal to it, but if deep it may so constrict the limb during embryonic growth that actual amputation in utero results, there being at birth granulation tissue or a scar terminating the stump

Treatment is for cosmetic reasons and to relieve the edema that results from interruption of lymphatic flow Merely excising the tissues of the groove and suturing the skin borders together fails, because the circular scar contracts, reproducing the constriction. Instead, after excising the tissues of the groove we should aim to create as broad and as long an approximation of subcutaneous tissue and skin as possible, by making diagonal cuts alternately in each skin margin to the deep fascia and undermining the skin and subcutaneous tissue for a distance in the plane between the deep and superficial fascia. The skin and whole thickness of subcutaneous tissue are brought together broadly and crowned, so that a zigzag juncture is made. This succeeds by avoiding a circular constricting scar, and furnishes maximal area of contact for reestablishing lymphatics. In some it is safer to work in two stages, doing half the ring at a time.

DYSCHONDROPLASIA

The metacarpals and phalanges may show effects of symmetrical aberrant growth, such as being short, curved, and with thick, irregular ends with multiple, knobby exostoses and deformities of joint surfaces, causing distortion. This condition does not show itself at first, but being a defect located in the parts about the epi

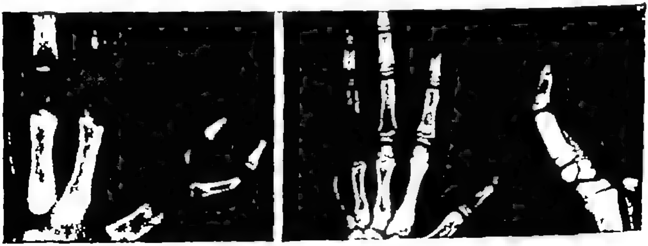


FIG. 704 Bifed thumbs.
(*Left*) Equal twinning of proximal joint.
(*Right*) Asymmetrical twinning of proximal phalanx and absence of all other digits.

FIG. 605 Three jointed thumb of each hand. (Courtesy Haas, S L. Amer Jour Roentgenol., 42 678 No 5 November 1939)

FIG. 606 Congenital hypertrophy with pigmentation of all toe and fingernails There is also thickening of soles (Courtesy of G F Van Demark M.D)

physeal plate that should produce bone growth, becomes evident as the child grows. It is not confined to the hand, but affects the bones throughout the body It is hereditary and associated with other congenital deformities, of which it is just another type

MEGALODACTYLIA

This uncommon deformity consists of hyperplastic, giant overgrowth of one or several of any digits, though usually of the long, index, or the thumb, including the phalanges, but usually not the metacarpals, and often with some lateral curvature. It is usually not associated with other deformities, is seldom bilateral, and usually not hereditary Some are due more to bony overgrowth with normal appearing soft parts and others more from abnormal excess of fat, lymphatic and fibrous tissue, like a tumor Large neurofibromata have been found in these digits frequently enough to suggest a causal excessive nerve trophic effect on the overgrowth.

When too unsightly, amputation is indicated. A giant finger may be amputated including its metacarpal and the hand narrowed by jogging the marginal ray into its place. The growth may be checked by destroying the epiphysis The abnormal fat and fibrous tissue may be reduced in size by multiple excision

ANGIOMATA

Arteriovenous angioma may be congenital in the hand and may be progressive, leading to trophic disturbances The vessels and multiple communications between arterial and venous systems may be demonstrated by radiography after injecting thorotrast under the application of a tourniquet. Amputation of the affected part may be necessary if it be a terminal part, such as a finger In the hand usually one can dissect out the tumor completely If involved skin or other affected tissue is preserved there may be difficulty in healing Skin grafts may melt away and more skin become involved

KNUCKLE PADS

Knobs on the dorsum of the fingers opposite the middle joints are not rare They may be the size of a bean and on a few or all of these joints. By palpation they feel as if on the bone, but by dissection are seen to be composed of thickening of all the tissues, ligamentous capsule of joint, and skin For this reason it is difficult to remove them. The ligament and under surface of

great from infant to adolescent life that scars made in infancy longitudinal with the lines of growth will not grow so rapidly as the rest of the digit or hand, and so will drag it into a curvature, contracture, or deformity If incisions must be made in infancy they should be transverse or widely zigzagged to allow for growth, instead of being longitudinal with the finger or limb

Whenever possible, conservative treatment is best in infancy, delaying surgery until bone centers have developed and the hands are larger By prolonged mild splinting or frequent new applications of plaster of Paris, many deformed limbs can gradually be bent straight and held so until they grow straight. Also deformities, such as Madelung's or from defect of a forearm bone or dyschondrosplasia, can be held in check.

Roentgen studies should always be made Bone centers may not be absent just because they do not show in early films. They may appear later if we wait.

A defect is a defect. It is impossible to replace parts that are missing and there is no natural tendency to grow them. We may build a post for a thumb, for the fingers to work against, but must usually merely modify for better cosmetics and function those parts that are already there

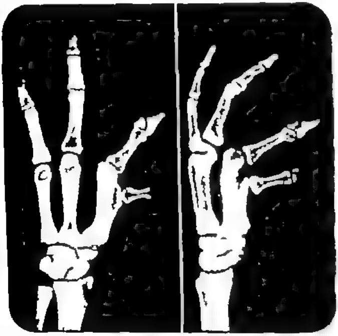
First the deformity must be overcome if not by splinting, plastic surgery on the soft parts is needed As the soft parts, muscles, tendons and nerves may share in the defect with the bones these must be considered by fasciotomy, supplying new skin or transferring tendons and muscles Tendon lengthening rather than tenotomy preserves the tendons for function In realigning bones to straighten limbs or make digits opposable, cuneiform or rotary osteotomy is used and bone grafts may be needed. In absence of thumb to furnish an opposing digit a finger is in this way turned about to face the others or a hand may be split and each part of it made to face the other A finger used for a thumb will be too long. Therefore, the growth should be stopped The epiphyses are on each side of the metacarpophalangeal joint and should be eradicated It is not enough to remove and replace, turned around, a small piece on each side of the plate, but the whole plate should be curetted out through an incision on each side The cavity may be filled with cancellous bone from tibia or ilium or chipped up pieces from the adjoining bone.

For mirror hand a selection may be made to have four fingers and one for the thumb discarding the other digits. Osteotomy of a finger so as to parallel the others and of the digit selected to be the thumb to oppose them, may be done It will be necessary to build a thumb cleft by adding a diamond dart of pedicled skin, and to furnish tendons to adduct and oppose the thumb and give lateral balance to the fingers.

In absence of fingers the metacarpals may be phalangized, using skin grafts for covering A cleft may need widening by a plastic zigzag or a skin graft, or widely divergent digits may be brought nearer by excising the intervening obstructions such as a metacarpal and similarly a broad hand is made narrower If a supernumerary marginal or central digit be removed its tendons should be spared for transfer to where they may be needed as in another digit or for a tendon loop or tendon T transfer to furnish adduction or for a pulley transfer for opposition. A finger should not be removed if it will spoil the adjoining one by removing half a joint or the only tendon or nerve between them

In operations on bones in the young we should to protect growth, keep away from the epiphyses and arthroplasties are best delayed to adult age, as excessive growth makes them unsatisfactory In children Pedicled skin grafts are not suitable for infants A free skin graft, however 010 to 012 inch, may be so deep that it removes the full thickness of skin in infants 014 to .016 at the age of six, and .016 to .018 at the age of twelve.

FIG. 710A. Ectromelus. (Courtesy of M S De Roy)



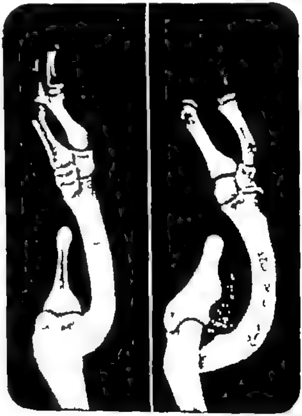


FIG. 710B (*Right*) Defect in ulnar ray fusion in carpus, and short and bowed forearm (*Left*) Defect in radial ray of hand and fusion in carpus. Hemi middle phalanx. (Courtesy of Henri S. Denninger Journal Medical Radiography and Photography)

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17

Vasomotor and Trophic Conditions

INTRODUCTION

A small proportion of the disabled hands that come for treatment show nutritional and trophic disorders other than mere loss of sensation and motor function. Some are purely nutritional from lessened vascularity due to actual vessel injury, vasospasm, or strangling of vessels by scar tissue. Others are from dysfunction of nerves other than the somatic ones, such as sympathetic and allied nerves, and some are from mental perversion such as hysteria. Often these etiologic factors overlap. In the second or nerve-dysfunction group are the cases that strain the patience of the doctor. Of these there are withered hands with excruciating pain, swollen, painful, useless hands that the patient will not move, hands that are discolored and dripping with perspiration, hands held in contracture or weird positions, and those the scene of many spells of vasomotor spasm, leading even to gangrene.

Let us first consider, however, the effect on nutrition of scar tissue, of lowered vascularity, and the trophic effect from severance of somatic nerves.

Congealed Hand from Cicatrix

We have already discussed the congealed hand that has been wrecked by trauma and the ravages of infection. Here, the resulting cicatrix strangles the blood and lymph vessels and the nerves, lowering their function, binding all movable parts and fusing the tissues into a firm mass. From the very low nutrition all tissues are impoverished, becoming thin and firm, and have small hope of recovery unless relieved by liberation from scar—both deep and superficial—and substitution of cicatrix by new vascular skin and subcutaneous tissue.

Effect of Lowered Vascularity

From loss of a main artery, such as a brachial or both radial and ulnar, there is loss of pulse and lowered nutrition. All tissues share in the atrophy. The limb is smaller and its surface cooler, and the skin becomes smooth and transparent. The whole limb is paler, though the digits later may be cold and reddish blue from stasis. Comparisons of color and coolness may be made with the other limb and with one's own hand, using the back of the fingers as the index for the gradations of temperature in feeling along the limb. Some show loss of the ends of one or more digits. Others have Volkmann's ischemic contracture, or a similar condition locally in the thenar or other intrinsic muscles of the hand. After both arms are raised and ligated and then suddenly lowered and the tourniquet removed, the return of red color is prompt in

the normal side, but slow and more intense on the side with vessel injury From insufficient blood supply there is tingling numbness, and even severe pain, especially on exertion or on keeping the arm raised Moderate edema develops and trophic changes show in the skin, hair, nails, and other tissues

If the injury is limited to just the vessels, collateral circulation will eventually restore the nutrition, but if, as in the usual case, there is in addition extensive injury and cicatrix throughout the soft tissues and nerves, this state of lowered nutrition is of long duration or permanent.

Vessel Injury Accompanied by Vasospasm. When blood vessels are injured there is often added another set of symptoms from reflex vasospasms, which leads to trophic and nutritional changes even surpassing the ill effects from injury to the vessel itself Vessel injuries are especially prone to set off this vicious reflex, and so it was that before this conception of the subject developed, from accurate observations Benisty named certain signs which indicated that vessel injury was present in addition to nerve injury These, that we now recognize as effects of vasospasm, are reddish purple or bluish black color cool, glossy, tense skin from which blood gushes forth on pricking, succulent, infiltrated tissues with hard nonpitting edema and with trophic, vasomotor, and secretory disturbances. These signs really did indicate vessel injury, but were due to the resulting vasospasm rather than to the injury itself

Thrombosis. From the work of Leriche, and later Ochsner and De Bakey it was found that vasospasm accompanies thrombosis and embolism, greatly accentuating the symptoms. *A widespread veno- and arteriospasm* is set up, adding to the effects of vessel block, increased pain, lymph stasis, edema, and fever Procaine blocking of the sympathetic ganglia one or several times often removed the superimposed symptoms.

Following direct injury, and lasting 48 to 72 hours, a limb may go into shock from reflex vasospasm. It is pale, almost pulseless and may even go on to gangrene. Sympathetic block twice or three times a day may restore circulation

Trophic Effects from Injury of a Somatic Nerve

The ventral cells in the cord and the cells of the spinal ganglia govern the nutrition of the part supplied When a somatic nerve is divided certain definite trophic *changes take place in the muscles, bones*, skin, joints, and all tissues supplied by it, as described in Chapter 8 Muscles undergo fibrous degeneration, bones—porosis, skin —shrinkage, smoothness, loss of sweat, joints—thinning of cartilage and loss of motion from shrinkage of ligaments. These effects are not necessarily due to vasospasm, but more to the loss of those nerve fibers supplying the structures In a somatic nerve are fibers of all kinds motor, sensory, pilomotor, sudomotor, and sympathetic, producing pain and vasospasm. *For the first three weeks there is vasomotor* paralysis and the limb is hot, flushed and dry Later it becomes cold, cyanotic and *its temperature is controlled not to vasomotor* response but directly by the temperature surrounding it. Thus, when severed, the tissues are affected in various trophic ways different from vasospasm

Lewis and others have shown that similar changes in skin and other tissues occur from lowered blood supply from disuse, irrespective of whether caused by lesion of motor nerves, fixation of joints or tendons, or even psychic disturbances. *The atrophy* and tapering of fingers from nerve lesions he claims is not trophic but is from disuse defective blood supply, and lack of sensation. Whatever the exact mechanism, however, trophic changes follow nerve severance.

The skin, joints, and other tissues are no longer protected by sensation from incurring the effects of trauma, and so they are

injured and are slow to heal In addition, these painless injuries may set up a vicious reflex vasospasm, resulting in much edema and degeneration of the tissues. Rough physiotherapy on insensitive parts quite commonly damages in this way

Painful Nerve Lesions. The above refers to nerves that are completely severed or physiologically blocked. These are not painful unless from their terminal neuromata, vasospasm or other reflex is set up It is the partial injuries of nerves that give rise to severe pain Partial severance, a crush or even a quite minor injury of a nerve is the type that makes a painful lesion. These painful nerve injuries are those causing trophic conditions and pain of far greater intensity than from any complete nerve blockage Such irritative, painful nerve injuries produce their dire effect by setting up, through reflex action, a dysfunction of the sympathetic, vasomotor, pain-carrying and allied nerve fibers, the somatic nerve being merely part of the pathway of these.

TRAUMATIC VASOSPASM AND NERVE DYSFUNCTION

Normal Protective and Heat regulating Reflexes. Normally, through the sympathetic nervous system and allied nerves, there is a constant play of reflexes through our limbs, and especially our hands, that protects us from outside injury and regulates the temperature of the body The hands in particular are sense organs, receptors of sensations of pain and temperature that guard us against injury and govern the reflexes controlling the flow of sweat and the caliber of blood vessels, either conserving or disseminating our body heat. Limbs constitute 65 per cent of our body surface so by flow of blood to or from the skin, and by evaporation of sweat, they have considerable effect.

Vasospasm an Exaggeration of Normal Vasospasm and dysfunction are but an abnormal exaggeration of these phenomena found in certain susceptible individuals and from certain stimuli Our hands and feet are the farthest from the engine box—namely, the heart and lungs—and the most exposed to excesses in temperature, so it is little wonder that in Raynaud s phenomenon, a dysfunction of vasospasm, cold is the greater inciter of attacks and that particularly the hands are affected There is rich arteriovenous anastomosis in fingers These phenomena so prevalently influence, control, or overlap the picture of the injured hand that a conception of this subject is a necessity in hand surgery The subject has been developed through the researches and writings of Leriche, Fontaine, Foerster, Benisty, Lewis, Smithwick, White, Homans, Livingston, de Takáts, Miller, Ochsner, De Bakey, Doupe, Mayfield, and others. The condensed résumé of the succeeding pages has been freely drawn from their works

The Phenomenon. Our conception of the phenomenon is in the formative stage, and is as yet not entirely clear The dysfunction occurs in various forms closely allied, but varying in having one or another aspect as the conspicuous feature, though each condition may show some of the many symptoms that are common to all. Among these, which vary in degree, are vasospasm, psychic disturbance, reflex pain, sweating, osteoporosis, atrophy, and edema. Thus some conditions, like Raynaud s phenomenon and acrocyanosis, are characterized by vasospasm, while in the other extreme in causalgia burning pain is so excruciating that it dominates the picture In others, the conspicuous feature may be hyperhidrosis blotchy skin, and excessive nervousness. Between these extremes are many forms of dysfunction due to minor injuries in which there is pain, edema, vasospasm, etc. They are, however, of the same phenomenon, to which the following names have been applied traumatic edema or vasospasm, Sudeck's atrophy or posttraumatic osteoporosis, reflex dystrophy of the extremities,

peripheral trophic neuroses reflex nervous atrophy, chronic segmented angiospasm and, as suggested by Homans, minor causalgia. These all refer to the same condition, even including Sudeck's atrophy,

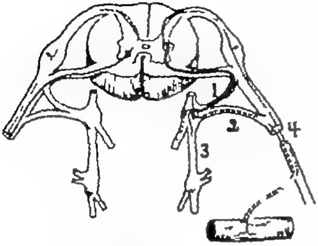

FIG. 711 Diagram indicating connections in vasomotor reflex arc between spinal nerves and sympathetic system.
(*Dotted lines*) Afferent fibers.
(*Dashed and solid lines*) Efferent fibers.
(1) Preganglionic fibers in white ramus.
(2) Postganglionic fibers in gray ramus.
(3) Sympathetic trunk and ganglia.
(4) Spinal nerve.
(5) Peripheral artery
On left, somatic reflex is indicated.

which is merely an exaggeration of one symptom—vasodilatation—and hence osteoporosis.

There is great variation in degree, from extreme cases to quite minor symptoms, many of which commonly can be recognized in our usual run of hand cases Some consider that the edema ordinarily accompanying sprains is of this nature, and routinely inject novocain locally at regular intervals to interrupt the reflex, though the merits of this are yet to be proved If we are alert we can recognize from the beginning the cases in which the true condition will develop and so can prevent it.

The theory is that there are special touch corpuscles or receptors, especially lying on the walls of the blood vessels, in nerves, in nerve sheaths, and in the periarticular tissues, ligaments, and tendons. Injuries to these parts, usually of a minor nature such as a strain or crush of the wrist, a traumatism to nerve or artery or even a pinprick of a finger, may through these receptors initiate a reflex to the cord and return causing peripheral vasospasm. Vasospasm is but an exaggeration of the normal tone of the muscular coat of a vessel. On snapping an artery, the latter is seen to contract This vasospasm is tonic and continuous. It causes pain, and this in itself incites more vasospasm, so the condition is a vicious circle and is self-perpetuating, spreading up the limb and increasing in intensity Vasospasm, pain, secretory, and perhaps trophic disturbances are all included in the reflex which, when kept up, produces edema, stiffening, trophic disturbances, atrophy, and neurosis. The condition may be transient or permanent—it depends somewhat on the state of mind of the patient.

On experimentally producing a painful spot on skin by trauma or by electrically stimulating a nerve, hyperalgesia will spread in a much wider zone (up to 20 cm) about it, even overlapping other nerve areas. According to Lewis, this is a set of nerves, different from sympathetic or somatic, which he calls nocifer (defense), and these cause to be released in the skin a substance causing itching hyperalgesia, and vasodilatation. A local anesthetic can dispel all at once.

It is probably such a focus as this wherever it is that acts as a trigger point to spread reflexes. The accompanying cerebral trauma also initiates reflexes through cord to periphery and the longer both the local and central stimuli last the harder it is to eradicate the reflex.

Effects of Breaking Reflex. These patients are neurotic, have continuous pain, refuse to move, and constantly nurse the swollen hand It has been found, however, that if this vicious nervous reflex be broken by injecting procaine where it intercepts the arc the pain and symptoms at once leave. The vessels dilate and the limb be-

comes warm This may last for hours, days, or weeks, but usually the injection must be repeated several times—preferably just before the reflex returns—and then it may be found that the reflex ceases for days, weeks, months, or even permanently

PHYSIOLOGY

Afferent Pathway The receptor cells in the vessel walls, acting in a thermoregulating system, are stimulated by cold or products of trauma or infection to regulate just how much blood a limb should have Thus surrounded by what is called Du breuil's "vascular atmosphere," they are sensitive to any change and can start the reflex. From the receptors, the small afferent nerves—whether sympathetic, vasomotor, or somatic and of sensation—travel only a short distance along the vessel walls and then pass over to the main nerve trunk (median or ulnar), to continue in it to enter the cord through the posterior roots

Efferent Pathway According to Smithwick, voicing the present conception, the efferent constrictors to the arm originate in the ventral horn cells, pass through anterior roots to the nerves, and then through the white rami to the sympathetic trunk, transmitting to the cells in the ganglia by synapsis. Then, by posterior ganglionic fibers through gray rami, they reach the cords of the plexus to follow down the nerves to the periphery, where they then pass over to the blood vessels just above where they terminate in these vessel walls. Probably all these nerves to the arm come from the second and third thoracic ganglia and possibly from the next few ganglia below these

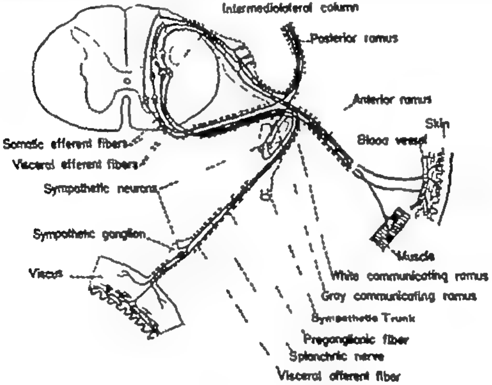

FIG. 712 Diagram illustrating visceral and somatic reflex arcs. (Courtesy Kuntz, Albert Textbook of Neuro-anatomy p. 326, Philadelphia, Lea and Febiger 1942)

Brain and Chemical Excitors. The above is supposed to complete the vasomotor arc, through which is transmitted the vicious reflex Brain centers also exert vasomotor control through these efferent pathways, there being a strong emotional effect, fear and anger constricting and shame and embarrassment dilating Chemical substances, under the influence of the nerves as suggested by Lewis, also act on the vasomotor muscles. Cannon showed that

sympathin is produced locally by nerve endings, and causes constriction. Similarly, dilating fibers may act, producing choline-like substances locally Sympathetic nerves act on the adrenal and other glands to set free vasoactive substances, which act generally

Vasodilatation and Constriction. Stimulation of the sympathetics causes constriction, and of a somatic nerve, dilation. Vasodilatation can be produced by severing nerves, arteriectomy, periarterial sympathectomy, and sympathetic gangliectomy, evidently all by removing the action of constrictor fibers instead of stimulating the dilators. Not much is known of the afferent vasodilator nerves for the extremities. According to de Takáts, they probably

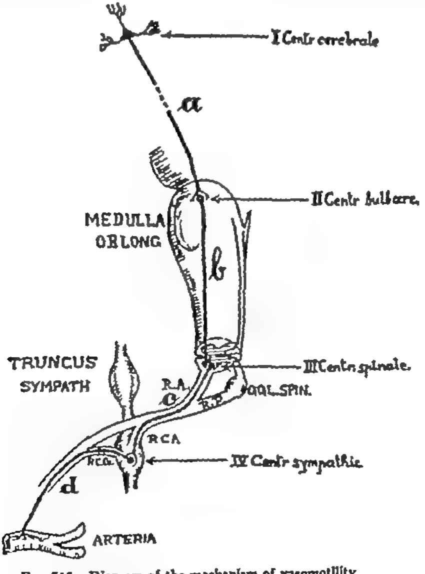

FIG. 713 Diagram of the mechanism of vasomotility
(a) Cerebrobulbar vasomotor tract.
(b) Bulbospinal vasomotor tract.
(c) Spinosympathetic vasomotor tract.
(d) Sympatheticomuscular vasomotor tract.
(I–IV) Primary and subordinate centers
(R.A.) Radix anterior
(R.P.) Radix posterior
(R.C.A.) Ramus communicans albus.
(R.C.G.) Ramus communicans griseus. (Courtesy, Bing. Robert Compendium of Regional Diagnosis in Lesions of the Brain and Spinal Cord, p 21, St. Louis, C. V Mosby Co.,

arise in the spinal ganglia and pass out the posterior root Some may go through the sympathetics When the sympathetics are out, the vessels of the limb are more sensitive to the action of adrenalin. Also, they are able to contract as usual, by means of their local mechanism. Sympathectomy may stop the pain, but it does not entirely abolish vasoconstriction.

Occurrence

In only a few instances does such common injury as strain, crush, partial laceration or infection of blood vessels, nerves, joints, or any part of the hand start the reflex of dysfunction, and only in those people who are victims of constitutional biologic inferiority They lack stability in their autonomic nervous system and are subject to both vasomotor and emotional upsets They are the sort that develop painful amputation stump, causalgia, epilepsy, and Raynaud's phenomenon. In this type of individual are found such ailments as erythromelalgia, angioneurotic edema, hives, acrocyanosis, hyperhidrosis, and various forms of neuroses Vasomotor spasm in such persons may occur in other parts of the body, such as the brain Frequently epilepsy (vasospasm of the cerebral vessels) and transient aphasia, blindness, or dizziness is found associated with Raynaud's vasospasm of the extremities. Often, too, nervous instability, such as Raynaud's phenomenon and insanity, is found associated.

Mental viewpoint and emotion, as well as cold and other local irritation, have much to do in perpetrating these dysfunctions, especially in liability and compensation cases. Though the condition is not primarily hysterical or malingering, these both may overlap the organic basis. The pain propagates vasospasm which, in turn, causes more pain and so keeps up this vicious circle that the patient's morale breaks under the continued pain

Sympathetic reflex including vasospasm accounts for the painful overlaps, which are continuous or come in paroxysms, that are often found following frostbite, burn, some brachial plexus injuries and even cervical rib, disc or pressure from the scalenus anticus muscle

Symptoms of Dystrophies in General

Pain Pain is the basic feature of all, and in causalgia reaches excruciating intensity In some forms there is less pain, but more edema and stiffness It accompanies all forms of venospasm, both in paroxysms of intensity and continuous with no letup It is the symptom to which the patients pay the most attention. Vasospasm causes pain and pain initiates vasospasm in continuous vicious circle It is probable that pain is from special sense organs different from, though associated with, those reflexly producing vasospasm. When there is surface anesthesia from dysfunction of somatic nerves, deep-seated pain may often be elicited from pressure Vasospasm is painful not only because arteries are sensitive, but in ischemia pain is the cry of the starved tissue. It is usually severe up to the time of gangrene. It may be from irritation of the receptors from altering Dubreuil's "vascular atmosphere." Sympathetic type of pain is described as burning, sweating, twisting, crushing, or stabbing It comes or increases in paroxysms, influenced by emotion or outside causes. The area is sore to touch on both superficial and deep pressure and sensitive to cold draft. The pain is usually in the area supplied by the median nerve, but readily spills over to the adjoining nerves and extends on up the arm.

Mental Due to pain, the patient concentrates more and more on his disabled hand, shutting out more of the world about him, until his eyes and attention are riveted upon it and all his efforts are to nurse and

protect it. Anticipation of rewards through litigation makes the disability a precious asset which, though, is right in line with his desire to avoid pain, and protect and cherish his disability. He inhibits all movements until the hand stiffens in its position of nonfunction.

Skin. The hand is either attenuated as in excessively painful states, or is swollen, smoothed, and rounded with edema. In the former, the skin is thin, smooth, and satiny to touch. The wrinkles and fingerprints are smoothed out. The fingers taper and are blotchy from pale to red, and have a cyanotic hue. In either type, the skin may be bluish red and so smooth that it is glossy. Being turgid with blood under stasis it bleeds on the slightest prick. The skin is usually dry but it may be moist, and in some the sweat runs so profusely that the skin is macerated in the folds of the palm and between the fingers. Sweating may be measured by Richter's skin resistance galvanometer or Victor Minor's starch iodine test. The color ranges from pale to blue black, as when cold, and is usually pale cyanotic. This depends on the state of vasospasm. The hand is always cold to touch, even though turgid with capillary blood, as from vasospasm the flow is slowed to stasis. For this reason, the skin and all the tissues are not only atrophied from lack of nutrition but changed throughout from the products of stagnation.

The nails grow deformed and irregular. They may be ribbed longitudinally or transversely, brittle and with cracks, and usually grow curved in both dimensions.

The hair usually falls out or becomes long and fine, though sometimes it is increased and in some it stiffens.

Blood Vessels. Arteries, when long under the influence of vasospasm, eventually thicken in their walls and their capillaries become varicose.

Limbs with painful dystrophies may be warm from vasodilation or cold from vasospasm. There is the tendency to commence with the former, but to end with the latter, at which time there may be, also, atrophy and endarteritis. Homans ascribed symptoms to vasospasm and de Takáts considered vasodilation to be the usual cause. The trend of opinion in painful conditions like causalgia is to consider neither spasm nor dilation as causal.

Bones. Bones become porotic first in the distal phalanges, but eventually throughout. This feature distinguishes vasospasm from arteriosclerosis, as in the latter the blood is insufficient to carry away the calcium. The porosis comes faster and is greater than in atrophy of disuse. It is from the vasodilatation which precedes or alternates with vasospasm.

Joints. Painful nerve lesions have great effect on joints which stiffen from immobilization, edema, and from vasospasm, due to malnutrition and infiltration with waste products. Cartilages atrophy and ligaments shorten and thicken.

Edema. Edema is a pernicious accompaniment of vasospasm, as it results in stiffness of joints and movable tissues and causes local malnutrition. Disuse, reflex from trauma, thrombosis, and vasospasm, increase it. The longer it is allowed to remain, the greater will be the stiffness, as the fluid of edema, which is rich in protein, deposits fibrin and binds the movable parts. Movement and exercise would drive away the edema, but instead from pain the patient holds his hand motionless. Should the injured part be at once immobilized and the surrounding parts kept moving, edema and the vasospasm reflex would in many cases not develop, as edema itself stimulates the reflex.

Lymph is kept flowing by the pumping action of the muscles and the beating of the arteries. Vasospasm and immobility stop it. From arteriospasm and the increase of capillary pressure from venospasm which augments filtration pressure, the blood stagnates in the capillaries and the lymph passes over into the lymphatics, where its

FIG. 714 Case A. M Aged 78
(A and B) Causalgia of two years' duration following a minor operation in palm Bitter complaint of burning pain in palm and fingers Holds hand immobile except for tremor with handkerchief between atrophic, sweaty fingers. Distal joints are ankylosed and proximal and middle ones have but a trace of motion.
(C and D) Some improvement in motion and feeling from several novocain injections of upper three thoracic ganglia.

protein content rises and it even contains some red blood corpuscles. Endothelial cells swell and there is transudation from the vascular to the perivascular spaces, filling the subcutaneous tissues until there is pressure atrophy of the fat. Prolonged edema becomes fixed, hard, and nonpitting

Muscles. The patient ceases to use the muscles as if from reflex inhibition, instead he holds muscle groups hypertonic. This is frequently seen as a defense reaction to maintain the immobility, the intrinsics holding the fingers straight and stiff, and with the thumb grouped together at their tips and the forearm muscles holding the wrist in flexion or extension and the fingers immobile However, on request to move the hand the patient will not obey

Nerves. Sensation throughout may be preserved, but usually there is hypesthesia, or the hand may feel light touch or be dull to pinprick. In many there is hyperesthesia or paresthesia. The area is often not in accordance with areas of nerve distribution and may be glove-like, though this does not mean that hysteria is primary

CAUSALGIA

Causalgia was described as early as 1813 by Denmark, in 1838 by *Hamilton*, and in 1864 by Paget It was Weir Mitchell in 1864 who wrote the classic description and Benisty who later elaborated upon it.

This is the dystrophy in which pain, not edema, is the overwhelming symptom. It is not an entity, but cases grade into the other forms such as the minor causalgias of Homans' and Sudeck's atrophy The major forms described by Mitchell were of war injuries to the brachial plexus, but the condition may follow even the puncture of a finger

Resulting from minor injuries, as mentioned above, it is found principally in the regions supplied by the median and sciatic nerves, though it may overlap into the ulnar area and extend up the limb to include in a few cases even the other arm. Occurring in about two per cent of nerve injuries, there were many cases in the military hospitals in World War II Injury of brachial plexus was the commonest cause The ulnar nerve was only rarely the site. The hand is held fixed with the fingers extended and the thumb adducted with them The joints may even ankylose so The distal joints may be in hyperextension The skin is thin, smooth, glossy and in its volar parts blotchy red The hand is emaciated, atrophied, and slender, not thick and edematous Burning pain, which is the diagnostic and primary symptom here, seems to be from an aberrant action of the sympa

thetic nervous system less associated with vasospasm than in the other extreme Raynaud s phenomenon, though some vasospasm is no doubt present. There may be excessive perspiration or none but the skin is often kept so wet by the patient that it macerates The pain may at once or in hours from the accident commence suddenly or may build up gradually Anesthesia is not present but there is loss of epicritic sense in the area of paresthesia and hyper algesia. In the early stage, according to de Takáts, blood flow is increased 30 per cent as shown by the plethysmograph, the skin temperature is up and the pain and hyperalgesia are local. This vasodilation which is accompanied by progressive osteoporosis, is followed in the later stages by a condition of cold, cyanotic skin, firm atrophic limb and stiffened joints The pain may remain local or progress up the limb and expand over the trunk each of the three reflex centers being involved in turn until it is cerebral Memory of the accident may play a part. Psychosis may overlap The course reaches its maximum in a few months Half of the cases recover spontaneously in about two years but others last many years. The following quotation from Weir Mitchell paints the pic ture

Its intensity varies from the most trivial burn ing to a state of torture which can hardly be credited, but which reacts on a whole economy until the general health is seriously affected. The part itself is not alone subject to a burn ing sensation but becomes exquisitely hyper esthetic so that a touch or a tap of the finger increases the pain. Exposure to the air is avoided by the patient with the care that seems absurd and most of the bad cases keep the hand constantly wet finding relief in the moisture rather than in the coolness of the application. Two of these sufferers carried a bottle of water and a sponge and never permitted the part to become dry for a moment. As the pain increases the general sympathy becomes more marked The temper changes and grows irritable. The face becomes anxious and has a look of weariness and suffering The sleep is restless and the constitutional condition reacts on the wounded limb exasperates the hyper esthetic state, so that the crackling of a newspaper a breath of air another step across the ward the vibrations caused by a military band or the shock of the feet in walking give rise to increase of pain. At last, the patient grows hysterical if we may use the only term which covers the facts. He walks carefully carries the limb tenderly with his own hand, is tremulous, nervous and has all kinds of expedients for lessening his pain In two cases, at least the skin of the entire body became hyperesthetic when dry and the men found some ease from pouring water into their boots. They said when questioned that it made walking hurt less but how or why unless by diminishing vibration, we can not explain.

In causalgia, vasospasm or vasodilation, any of which may be present, are not productive of the pain, but accompany pain. The characteristic burning pain (hyper pathia), according to Doupe and his col leagues, flows up the sensory nerves from the periphery The pain impulses arise at the point of nerve injury and flow distally through the sympathetic fibers to the pe riphery Here through the coinciding sym pathetic and somatic fibers the impulse is passed over to flow up the sensory nerves. The reflex causes trophic changes in the skin and the interchange of impulse takes place in the skin as a vicious circle It is the skin of the hand that the causalgic wets and protects Impulses may originate else where in the sympathetic nervous system and travel to the periphery for transmission. By this theory pain may be psychogenic, causalgic or dystrophic, the latter meaning due to disturbances of nutrition in the extremities. The theory explains how activation of sensory from sympathetic fibers may be associated with emotional sudomotor pilomotor or thermal reflexes The occurrence of pain from the time of stimulation shows a delay of one or two seconds.

SUDECK'S POSTTRAUMATIC OSTEOPOROSIS AND ALLIED POSTTRAUMATIC REFLEX DYSTROPHIES

The condition bearing his name, which was first described by Sudeck in 1900, is less of an entity than a grade or type of posttraumatic dystrophy, in which osteoporosis is the prominent symptom Therefore, all are considered together, giving due emphasis to the porotic aspect under that subheading

In these hands the pain and loss of function is out of proportion to the trauma The causative types of trauma are mild and of the kind described above, especially of the wrist joint and periarticular structures Occurring less in fractures or greater injuries, where adequate splinting is used, it seems more often to follow crushes or wrenches, where splinting has been omitted and consequently pain and edema have been great and long continued.

The pain, swelling, and disability increase with paroxysms of greater intensity until the condition becomes chronic. It may pass in a year, as hypersensitivity from injury often does, or it may in extreme cases continue with stubborn, spreading pain and a growing negativism for the affected limb until, from fixation of attention, the morale lowers to the point of amputation of the limb or self-destruction.

The smooth, swollen, painful hand, edematous and cyanotic, is held immobile and carefully guarded by the patient. The wrist and fingers are usually semiflexed the muscles are on guard to prevent any movement of the joints the patient complains of tenderness to touch, of pain on movement, and steadfastly refrains from moving the joints himself The edema is throughout the limb and even in the joint capsules which thicken and shorten, limiting motion An edematous hand held immobile stiffens in all its movable tissues, joints, tendons and muscles, as explained in Chapter 7 Articular cartilages atrophy until in some cases synostosis may form at the carpal and finger joints The state of mind influences the hand, which is worse in emotional upsets and worry states, and the condition of the hand influences the patient until he seems content to be a charge on the community With all, pain of the sympathetic type is always a conspicuous feature

Osteoporosis

Normally, closely following a fresh injury, there is vasoconstriction in the limb for a few hours and then vasodilatation as an aid to healing for several weeks With chronic irritation, as from an unsplinted painful injury, vasodilatation is exaggerated, together with edema and pain and immobility, due to muscle hypertonus. This, in susceptible people, leads to Sudeck's atrophy There is an exaggeration of the normal reaction. Local temperature is increased As tested by Miller, the oscillometer shows high waves and from the plethyamograph there is an average of 30 per cent rise in these cases, showing an increase in blood flow Hypervascularity causes decrease in calcium in bones and especially in the metaphyses, the carpus and heads of metacarpals where it is greatest, which explains the rapid development in some of osteoporosis in the course of a few weeks In these cases the limb is warm and flushed during establishment of the porosis, but in the later stages is cyanotic and cold, atrophy and osteoporosis of disuse carry the process farther Such bone is too weak and, like the joints, pains so on stress that the limb is held useless It is important to recognize these cases in their incipiency and to prevent the condition from becoming established. The prophylaxis and treatment may be found at the end of this chapter

PARALYSIS WITH CONTRACTURES

Closely related to the posttraumatic dystrophies just described are hands, also post traumatic, where the prominent feature is that they assume and stubbornly maintain peculiar attitudes, and seem to have no power of movement These attitudes and contractures are quite varied "accoucheur's hand," "fist hand," "holy water basin hand" with hollow palm and half flexed fingers, flexed wrist with fingers extended, etc. They are painless unless the position is forcefully changed Fixed vicious attitudes and contractures disappear under a tourniquet or an anesthetic, but afterward are immediately reassumed. In some there is exaggeration of motor impulse, contracture, tics and tremor and in others diminution (paralysis)

Accompanying are the other symptoms of vasomotor and secretory disturbances tissue atrophy, coldness, cyanosis, blood stasis with lowered oscillations, moist or macerated skin, decalcification, hypotonia of some muscles and hypertonia of others without muscle atrophy, with lessened electrical reaction, but not with reaction of degeneration. These cases seem to be a mixture of posttraumatic dystrophy and functional neurosis from bad suggestions in susceptible people with defective mentality The inciting cause may have been some pain but mainly just a flight from reality, and a cure may follow disagreeable electric treatment with constructive suggestive stimulus.

Great edema in hands and forearm can be produced by malingerers by hanging their arms immobile for 4½ hours or longer as reported by Williams in beggars Elevation relieves except in cases of long duration which become permanently stiffened in the joints

RAYNAUD'S PHENOMENON

Raynaud's phenomenon is not a disease, but the effect of great systemic vasomotor instability It is an exaggeration of the physiologic thermal control of the sympathetics The patients are usually of neurotic emotional type, often showing other forms of vasomotor instability As the limbs are the thermal regulators cold is the usual irritant to start a paroxysm, placing the hand in water at 15° C. being the surest stimulus Attacks are also initiated by trauma or from sudden emotion, such as fright, excitement, or worry In these cases, therefore, there is real danger in operating on a hand, lest the operation be blamed for the loss of the fingers. In an attack there is first arteriospasm in one or several fingers, making them look like alabaster and accompanied by great pain This is usually quite transient and soon the color becomes ashen and then cyanotic. As the attack ends the fingers are bluish red and finally red and warm This sequence is not always followed. In an attack the hand is cold, the oscillometer waves small, and the pain great. The duration of a spasm may be short or even for several days and if the tissues are impoverished long enough a bleb followed by an ulcer, which is very slow to heal, forms at the end of a digit. If more severe, gangrene follows, the line of demarcation forming anywhere in the length of one or more fingers It is usually, but not always, symmetrical

The first attack may be the only one or attacks may come in great number until all four limbs, and even the nose, are shortened. From repeated attacks there is osteoporosis of the phalanges, especially the distal ones and thickening of the arterial walls. The fingers show the usual trophic signs of impoverishment from vasospasm. Thrombosis is a secondary factor With a hand lens the capillary loops in the fingernails can be seen as varicosities.

Landis found the capillary pressure to be only 5 mm of mercury compared with the normal of 40 In arterial spasm the capillaries once filled show stasis.

PAINFUL AMPUTATION STUMPS

Pain in amputation stumps is frequent, especially from the third month through the first two years Some is caused from cicatrix binding the skin to the end of the bone and some from neuromata that are bound in scar, pulled upon by muscle action, or irritated due to their axones which reach out into the tissues. Neuroma formation is normal, and, in a clean amputation, usually painless, but when in scar from crushed or infected tissue the neuroma is frequently painful The pain may be from anoxia of the nerve fibers in scar or be from mechanical attachment and compression Certain individuals show excessive tendency to regrow neuromata. In some of these, neuromata are quite large and round and a few are branched like the roots of an oak tree Pain in stumps from scar or ordinary neuromata is relieved by completely excising the scar and treating the neuromata, as described on p 375, excising, ligating, and displacing it into good tissue Disappointment follows if a nerve is merely freed or treated without radically excising the block of scar tissue and remodeling the stump Time alone remedies many painful stumps and the consciousness of their presence fades. When one no longer dreams of himself as a two-armed man his pain will be over

The truly painful stumps resemble cases of causalgia. The pain is steady or comes in paroxysms initiated by cold, emotional upsets, local trauma, or at times it is just cyclic without external cause. It is not located in any one nerve as in painful neuroma, but is throughout the whole limb Occurring in those emotionally intemperate and with vasomotor instability perhaps the haunting memory of the accident fans a neurosis The pain is burning, gripping or shooting in character, and referred to the lost hand which feels twisted or cramped as in a vise. It feels as if the fingers were in tight spasm and could not be moved, just as described by Livingston as the phantom limb syndrome Such torture lasts for months or years, and breaks down the morale. Scars and neuromata are resected and reamputations performed Whatever is done is successful for about three months, and the pain is back. Finally, nerves or posterior roots are resected and even the lateral bundles severed in the cord, but with no better effect because by then it is too late. Already the pain has worn a pathway to the brain which itself has become the seat of pain If symptoms are not relieved by brachial plexus procaine block as a test, the pain comes from higher A strange case, which finally cleared, occurred in the leg stump of a paraplegic of D 10

Pain is at first local, running up the nerves through the posterior roots and returning, starting the sympathetic reflex. It can be stopped temporarily by applying a tourniquet high on the limb If checked early it may not become cerebral There may be a trigger point that can be removed This often is a neuroma in scar that has started the reflex. In a case where three neuromata were removed from a forearm stump without relief, excision of a patch of cicatrix not near the nerves cleared the causalgia. When the nerves are injected with novocain the amputated limb is no longer felt. By local injections the exact tender spot where the neuroma, vessel, or scar which starts the reflex may be located and then remedied by excision Some are against any local operation in such stumps. When, however, done surgically, excising scar and treating and displacing neuromata it is successful in many early cases. Repeated excision of neuroma or amputation are useless Subclavian periarterial sympa

thectomy was used, but it is better first to test by procaine injection the upper several thoracic sympathetic ganglia. One to several injections may break the reflex for long or permanently The limb becomes warm and flushed, the pain leaves, and the patient states that his fingers have relaxed from their spasm and he can move them. Encouraged by this, if the attacks do not stop, severing of the rami or excision of the second and third thoracic ganglia is indicated

Causalgia, phantom limb and painful neuroma each have a different origin of pain. Though overlapping in symptoms, and sometimes coinciding, they are, when typical, separate entities.

TREATMENT OF POSTTRAUMATIC DYSTROPHIES AND VASOSPASM IN GENERAL

The various posttraumatic dystrophies and vaso and secretory disorders are treated in the main similarly, using orthopedic methods, mental suggestion, and measures to break the nerve reflex of vasospasm and pain. The former are especially essential in Sudeck's atrophy and the various minor causalgias, while the reflex breaking is paramount for causalgia, hyperhidrosis, and Raynaud's phenomenon.

Prophylaxis

By recognizing the potential cases early, prophylactic measures will forestall the development of disability from these causes The complaint of severe pain often in paroxysms is the early characteristic symptom, occurring as it does in the neurotic, vasomotor unstable type of person. In an injury of the dignity of fracture or greater the limb will be splinted, heading off the condition, and thus stopping the pain and edema before it develops. It is the *sprain, crush laceration, puncture, and minor vessel nerve injury* that are usually not splinted that lead to Sudeck's atrophy and the causalgias. Therefore, all sprains and such minor injuries should be splinted for three weeks. Only the injured painful part should be immobilized to stop pain and the remainder of the limb should be used, as usual, to keep away swelling This *functional treatment can be readily done* by the nonpadded cast, trimming it enough so the motion of any uninjured part, digits or thumb, is unhampered This determines whether the limb on removal of the cast will be stiff and painful or limber and painless. If minor or joint injuries are unsplinted continuous movement causes much swelling and pain which may start off a Sudeck's atrophy or causalgia. As a reflex prevention, in a suspicious case, novocain *locally can be tried.*

Treatment When Established

When such a case comes late and already the painful dystrophy has been established the painful digit or wrist should be splinted and active use of the arm and hand started. With cessation of pain by immobilization the patient will use the limb and the swelling and soreness will leave. After a month or so when the cast is removed the ligaments *will be built up, lime will be back,* and the pain gone. The patient must be convinced that only by use can he toughen up his hand sufficiently to be able to work. Gurd and Fontaine report cures in Sudeck's atrophy by these measures in the average time of six months. Not all cases are so easy Already the pain may have spread through the limb, joints may have stiffened, and the patient may have adopted the disability state of mind. To refer the patient to the physiotherapy department for treatment by heat, cold, massage, and diathermy repeated each day is useless, harmful, and fills the patient with suggestions of disability Forceful manipulation, with or without anesthesia only increases the pernicious nerve reflex, causing pain, swelling, and stiffness. If the condition is allowed to

progress, it may become fixed, the over worked pain pathways to the brain having changed the brain itself to pain producing In these cases there is mental overlap needing wholesome, suggestive treatment, and the reward should be for getting well instead of for remaining disabled The patient must exert himself to climb out of the neurosis factor and does so better when a suit is settled than when still impending

Trigger Point. A search is first made for the trigger point which started the vicious reflex Location of tenderness is a guide, though the surer method is to inject the spot with 1 per cent novocain solution If the correct spot is reached, the pain goes and the patient will relax his spasm and move his joints The relief may be for hours or for overnight.

If the offending part is a joint, immobilize, if a neuroma, blood vessel, nodule, or plaque of scar, correct it surgically, as described under painful amputation stumps If it is any deformity that by strain makes pain, correct it orthopedically In view of causalgia, operation should be undertaken with caution and not without good reason Removal of a painful neuroma, plaque of scar, or the freeing of a nerve is justifiable once. If unsuccessful, then it is folly to repeat. These measures often cure by removing the cause of the vicious reflex.

Break Reflex Arc by Injections of Procaine. Having eliminated the starter or trigger point, the reflex arc should be attacked. One may start with injections locally and then inject about the adjoining blood vessels or nerve. This is best for localized causalgia, and when the correct location is injected the pain goes at once. Credit is due to Homans for his pioneer work in this

The median and ulnar nerves can be injected just above the wrist and the ulnar nerve at the elbow 2 per cent novocain being used.

The tissues about the radial or ulnar arteries depending on which side of the hand is affected, have been infiltrated for a distance of several inches opposite and just above the pain site It will be remembered that from the site in the tissues the nerves go to the periarticular plexus From here, where there are more receptors, the nerve fibers travel but a short distance along the artery and pass to the adjoining nerve to reach the cord

The relief may be sudden and complete and last for hours or days If it is successful, it should be repeated two or three times a week or even daily if necessary until cured. The pain and vasomotor reflex is unstable and easily broken up It requires a certain time to reform—hours, days, or more. Often when it is broken it may not return at all or return to a lesser degree. It may recur from a later traumatism. If relief is short, repeated blocks will not help The longer the relief, the better is the chance of a cure. Each subsequent injection is best given just before the reflex returns and in that way the reflex finally gives up and goes.

Unfortunately injections into the nerves or periarterially, have so often failed that the routine custom now is to proceed at once with the ganglion block. Twenty cc. of a 1 or 2 per cent novocain solution are injected into the vicinity of the upper several thoracic ganglia. This is easy to do either by the posterior or anterior approach.

The effect is definite. The limb becomes warm and flushed from relaxation of the constrictor spasm. The burning pain leaves, the muscles relax from spasm, and the joints can be moved voluntarily and passively as far as their intrinsic stiffness allows The limb becomes dry and the skin temperature is raised. Enophthalmos and miosis or Horner's syndrome shows on that side. Injection of ganglia has greater effect and lasts longer than the lower block.

A successful ganglion block is diagnostic. Occasionally several such blocks suffice to make a cure, but in a goodly percentage there is improvement but not permanent

relief Direct surgical attack at the ganglion is the next step indicated With the assurance furnished by a successful block, improvement, or in many even cure, may be anticipated by the preganglionic sympathectomy which at present seems to be the method of choice. Section of the brachial plexus and severance of the posterior roots *have not been successful, nor has cordotomy*, though lately Smithwick claimed that if the spinothalamic tracts are severed as high as the second cervical segment, there will be relief of only pain and temperature *sense to as high as the fourth or fifth cervical* segment. Of a few extreme cases, though experimental, there has been report of relief from resection of post central gyrus or prefrontal lobe.

Ganglion block and sympathectomy are used extensively to relieve persistent pain and to improve blood supply The limb warms and sweating stops. By it improvement has been seen in cases of painful Volkmann's contracture and in painful conditions of arm and shoulder In one case of a pianist with painful muscle contracture, there was enough relief of spasm so that he could spread the fingers for playing from *5 to 6½ inches It has helped in hands with* lowered vascularity from vessel obstruction or vasospasm In Raynaud's syndrome there has been improvement especially in the healing after necrosis of the digits and in lessening of the pain. Color changes and susceptibility to cold, however, are not entirely eliminated

Tetraethyl ammonium chloride (Etamon) injected intravenously is supposed to block *the autonomic nervous system* Reports, at present on its value are conflicting

Local Limb Shock. After a severe injury of an extremity there is sometimes a question as to whether or not the limb will survive due to a primary vasoconstriction which renders the limb pale and cold *Immediate improvement has been reported in* these cases after several routine novocain injections of the sympathetic ganglia.

Causalgia has been difficult to control. In World War II most were relieved temporarily, and a few permanently, by one or several ganglion blocks, and of those on which sympathectomy was performed many showed decided improvement and many were cured. Cases with typical burning pain that were relieved by a test of procaine ganglion block responded well to preganglectomy, most all of them being relieved. The great majority of patients stated that most of their pain was gone. Some retained local hyperesthesia. Many *of those treated more conservatively* also improved or were relieved, especially when encouraged to make active use of the hand preferably at first under water starting under the protection of ganglion block *Some were cured by excising the trigger* point, be it neuroma, nerve in scar or just a patch of scar It seems that any of the above procedures may serve to break the reflex. Some were cured suddenly and others after some procedure which started them on the road to improvement.

After ganglion block or sympathectomy, the limb warms from vasodilation and sweating stops. The muscle spasm or ten*sion is relieved, loosening up the hand for* use. Then is the time to use the hand. In so doing, the joints, tendons and movable parts will loosen up, and, also of value to a patient is the fact that he will reconnect his hand to his brain from which it has been ostracized Activity in the occupational therapy department is most valuable Even those creative endeavors, such as sculpturing painting etc., which do not involve strenuous movements as exercise, serve to again place the hand under the control of the brain With this encouragement the *patient may proceed* in the use of the hand. It is advisable to commence treatment of causalgia as early as discovered to prevent joint stiffness, dissociation from the brain and extension of the reflex to higher levels after which it may become irreversible.

Technic of Injecting Ganglia Posterior Approach. With the patient prone and a pillow under the chest to arch the neck forward, a spot is marked over the tip of each transverse process of the first, second, third, and fourth thoracic vertebrae Injection locations are from 1¾ inches to 2¼ inches lateral to the spinous processes according to the size of the person, and each is opposite a spinous process, starting with that of the seventh cervical The needle is thrust vertically to the tip of the transverse process and then is deviated medially about 35° and thrust about two inches farther to hit the anterior part of the body of the vertebra, just over which the ganglia rests On the way, the ribs may be felt If too mediad spinal fluid may come through the needle, and if too lateral there will be cough and taste from puncture of the pleura If a nerve is hit, pain will extend around the chest Draw the plunger back a little to test for blood or air and inject and repeat until each of the first three or four thoracic ganglia have the 20 cc. of 2 per cent novocain solution distributed near them

Anterior Approach If 20 cc. of a 1 or 2 per cent novocain be injected in the neighborhood of the stellate ganglion, the solu

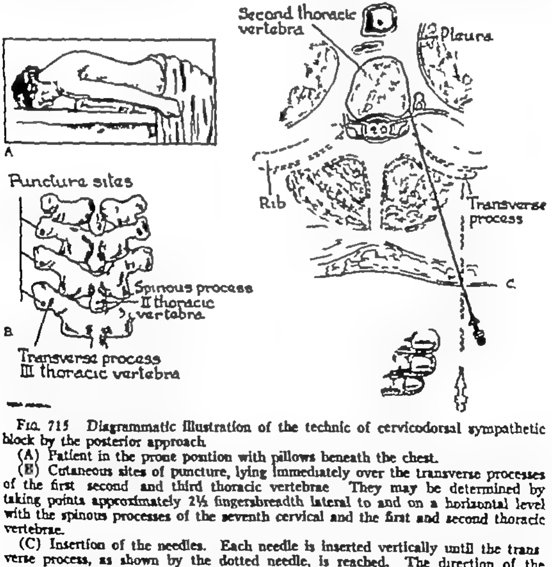

FIG. 715 Diagrammatic illustration of the technic of cervicodorsal sympathetic block by the posterior approach

(A) Patient in the prone position with pillows beneath the chest.

(B) Cutaneous sites of puncture, lying immediately over the transverse processes of the first second and third thoracic vertebrae They may be determined by taking points approximately 2½ fingersbreadth lateral to and on a horizontal level with the spinous processes of the seventh cervical and the first and second thoracic vertebrae.

(C) Insertion of the needles. Each needle is inserted vertically until the transverse process, as shown by the dotted needle, is reached. The direction of the needle is then changed slightly toward the midline and the needle is inserted 2½ fingersbreadth beyond the transverse process, so that the point of the needle is near the anterolateral surface of the body of the vertebra in the retropleural space, where the sympathetic chain lies. Five cc. of 1 per cent procaine hydrochloride solution is injected through each needle (Courtesy Ochsner and De Bakey Arch. Surg., 40 227 No 2 February 1940.)

tion will diffuse downwards in the soft areolar tissue until the sympathetic ganglia supplying the arm are anesthetized The stellate ganglion, with branches to C 7, C 8 and T 1, is 1 to 2 cm long consists of a fusion of the interior cervical and first dorsal ganglia and is located in front of the transverse process of C 7 and the neck of the first rib It lies between the dome of the pleura and the great vessels of the neck. The vertebral artery is anterior The ganglia rests on the prevertebral fascia covering the longus colli muscle just in front of the spine It is in loose areolar tissue which extends down around the sympathetic chain

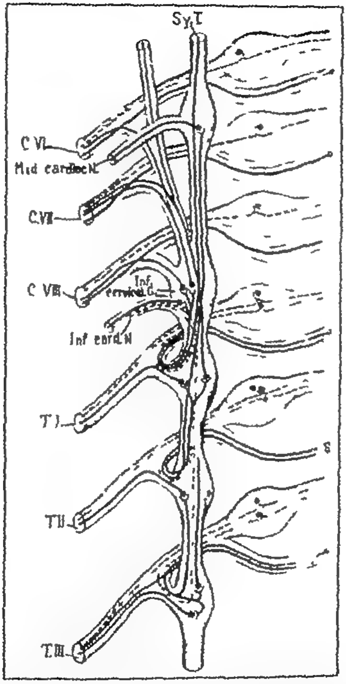

Fig. 716. Diagram showing the arrangement of the preganglionic and postganglionic efferent and visceral afferent fibers in the upper thoracic and lower cervical portions of the sympathetic trunk. (Courtesy Kuntz, Albert Textbook of Neuro-anatomy p 332 Philadelphia, Lea and Febiger 1942)

Directions for injection have been given by Leriche, Fontaine, Lamont, Ochsner, De Bakey, Murphy and others as to how to avoid the vulnerable structures in the vicinity, but Pereira showed that by placing the finger on the palpable transverse process of the sixth cervical vertebra the great vessels were shoved away medially and a 24 gauge needle could then be inserted without danger directly against the base, not the tip, of that process The patient is sitting so gravity will help downward diffusion Ganglia T 2 and T 3 should be anesthetized as these supply the arm. Injection at the tip of the sixth transverse process anesthetizes the brachial plexus. The needle point is held against the base of the process and the skin and muscles are allowed to resume their former positions. The needle then angulates until it is in almost a transverse direction. Five cc. of a 1 per cent novocain solution are injected at the bone The needle is withdrawn 2 or 3 mm until felt to be out of the prevertebral fascia and 15 to 20 cc. more are injected If in 15 minutes the arm does not react, Pereira (see Bib) advises to inject again after reinserting the needle tip 1½ to 2 cm. lower against the seventh transverse process This is also slightly deeper Five cc are injected there and 10 cc. 2 to 3 mm in front of it. If both sides are injected at once, there will be respiratory embarrassment from the phrenic nerves

Periarterial Sympathectomy In this, which has been particularly advised by Homans, the loose nerve-bearing tissue about a segment of an artery for several inches in length is excised including not the adventitia but the veins and tiny nerves passing from tissues to artery and from artery to the main adjoining nerve some of which are visible. When the artery is in scar tissue or shows contraction a segment of it has been removed in addition to its surrounding tissues. If the pain has spread too widely the chances for success are less. The subclavian artery has been stripped for a high lesion and for vasospasm from cervical rib

Herrmann and Caldwell report results in 34 cases of Sudeck's atrophy treated by periarterial sympathectomy In all pain left in 24 hours and edema in a few days They averaged three months to return to work compared with nine months when treated by physiotherapy Periarterial stripping has given way to sympathectomy

Sympathectomy This operation is resorted to after first testing the effect of injecting the ganglia It is not necessary for the minor grades and should not be done unless improvement from injection was definite The effects are, of course, more lasting than from injections Removal of the stellate ganglion, formed by the inferior cervical and first thoracic, has been found not to be necessary as this did not affect the arm As shown by Smithwick and others, sympathetic ganglia T 2 and T 3, and perhaps some below that by fibers running up the sympathetic trunk, are the only ones that affect the arm It is not necessary to remove any ganglion as a complete and more lasting sympathetic block of the arm can be gained (Smithwick and Telford) by interrupting only the nerve pathways of the reflex arc, that is, segments of the second and third thoracic nerves, the gray and white rami connections to the ganglia and by interrupting the sympathetic trunk between the third and fourth ganglia. The sympathetic nervous system has great power of regeneration (demonstrated by Kirgis and Ohler) Therefore, Smithwick and Telford removed the nerves intraspinally, cutting the posterior root proximal to the spinal ganglion and evulsing the ventral root Also the sympathetic trunk, severed between the third and fourth ganglia, was turned up into the muscle above and enclosed in a protective cap of silk. A segment of each of the second and third thoracic nerves was removed from within the forearm as above to beyond their rami to

the ganglia, *severing connections from the* lower thoracic ganglia by cutting across the trunk beneath the third. Horner s phenomenon is avoided and regeneration compared with other types of sympathectomy is much delayed and lessened The results on the arm are definite, and regeneration, when it does come, is only partial

The approach (Smithwick) is through a paravertebral incision 7 cm long and 5 cm from the midline opposite the second and third dorsal spines Muscles are split to allow removal of the 4 inner cm of the third *rib after cutting off* the tip of the transverse process. On separating the pleura above and below, the third and second thoracic nerves, the sympathetic trunk and ganglia and the spinal foramina are brought into view Following this sympathectomy the arm is dry and warm, but between the third and fifth day it perspires and cools By the second week the skin is again dry and cools, but *warms again in a week or two In the* subsequent months sweat glands do not act skin temperature remains up It gradually lowers in the course of many months

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18

Tumors of the Hand

By L. D Howard, Jr., M D

INTRODUCTION

This chapter on tumors of the hand is not intended to be an exhaustive or detailed treatise on the subject. Its main purpose is to acquaint the reader with the fact that tumors do occur in this region and to emphasize that their surgical treatment requires the same careful, meticulous dissection and avoidance of trauma which characterizes the treatment of other conditions of the hand All tumors which occur on or in the hand may occur in other parts of the body and, therefore, the details of the pathology of the more familiar ones are presented but briefly

A few tumors are seen more frequently in the hand than elsewhere, examples being glomus tumor and the enchondromata. Malignant tumors of the hand are rare, but when they do occur, due to their peripheral location and early diagnosis, they afford a good chance for cure. Because the hand is a compact, highly specialized mobile unit of the body, tumors in this location frequently lead to limitation of function as a result of mechanical interference, and this is often the presenting symptom. In addition to the solid tumors, ganglia and cysts are also included as they are quite common and arise frequently in the differential diagnosis The presentation of the material does not follow any set system, either by tissues or by region, but in general the more commonly encountered tumors will be considered first. It is hoped that the references at the end of the chapter will serve as an introduction to the literature.

EPIDERMOID CYSTS

Introduction and Historical. Epidermoid cysts were first described by Rizet in 1866 and he gave to them the term "dermoid cyst." These epithelial structures have been recognized as clinical entities for over 60 years. They are commonly called implantation cysts or implantation dermoids. They are of special interest due to their occurrence in industrial workers and in some instances following operations They were first called epidermal cysts by

Troquart in 1881, as he found there were no true skin papillae in the lining Observations were made that these cysts developed secondary to injury and gradually the conception of implantation of epithelium

Fig 717 Hard white tumor in subcutaneous tissue for two years proved to be a many layered skin inclusion cyst.

became evident Other authors stated that the cysts could occur without trauma and supported the view that they were the result of embryonal cell rests These cysts are known under various names due to the interest taken in them, and the literature contains such terms as epidermal cyst, pearl tumors, dermal cysts, implantation dermoid, etc. King prefers to use the term "posttraumatic epidermoid cyst."

Etiology These cysts are now generally accepted as implantation phenomena due to the frequency of history of a wound preceding the development of the cyst, the fact that they are lined with squamous epithelium, experimental implantation of the epidermis producing similar cysts (E Kauffman), and also the observation that they occur postoperatively near scars. There are some instances in which there is no history of trauma or operation and the etiology of these, as previously stated, has been explained only by theory The cysts are generally not considered dermoids, as they do not contain products of the skin, namely, hair or teeth

Pathology On gross examination these cysts are round or ovoid and have walls from one-eighth to one-sixteenth of an inch in thickness. At times they may be lobulated if their location is such as to be constricted by fascia or other structures. They are filled with a white material having a crystalline sheen which, on analysis, shows high cholesterol and low fat content and in this way the material differs morphologically and chemically from that in sebaceous cysts On microscopic section, the wall is observed to be of fibrous tissue, with an inner lining of squamous epithelium which in areas shows laminated keratin The epithelium is without papillae in its basal layer and in the adjacent connective tissue some foreign-body giant cells are usually seen At times the epithelial lining is not complete.

Incidence. These cysts occur most often in persons who traumatize their hands in their occupations, such as laborers, carpenters, gardeners, etc. The average age in one series of reported cases is 41 years, the limits being 18 and 64 years. They are more frequent in males, as might be expected While these cysts are generally single, they may be multiple.

Location. The palmar aspect of the hand and fingers is the most common site A history of crushing or laceration of the skin of this area or a history of penetrating wounds can be obtained in as many as half the cases In rare instances the cysts may

Fig. 18 Large epidermoid cyst in proximal segment of index finger On removal the specimen measured 18 x 9 x 7 mm. (Wakeman U S Army photo.)

occur in the distal phalanx. Such cases are reported by Yachnin, Summerill, Pohlmann and Wachstein

Symptoms There is generally a latent period, varying from a few months to several years between the time of injury and the clinical manifestations of the cyst. There often first appears a small nodule or thickening at the site of injury followed by a period of enlargement as the cyst increases in size. There is seldom pain, although tenderness may be present, especially during the growing period.

FIG. 719 Epidermoid cyst Photomicrograph of portion of the wall showing excessive keratin formation. Cysts of this type were, no doubt, the reason for the term "cholesteatoma" which was applied to these cysts (× 26) (Courtesy King E. S J Brit. Jour Surg., 21 38 No 81 July 1933)

Diagnosis These cysts present as rounded, semifluctuant elastic tumors that are generally not adherent to other structures. In the finger, they may be ovoid in shape. The history of an injury and of the latent period before development is usually obtained, and if the cyst is aspirated a thick greasy material or granular with cholesterol crystals is withdrawn These cysts rarely become infected, and the principal differential diagnosis is between foreign body granuloma, ganglion, and xanthoma

FIG. 720 Photomicrograph showing the wall of an epidermoid cyst with spaces and giant cells in the connective tissue, which is covered by a very low poorly developed squamous epithelium forming keratin (× 150) (Courtesy King E. S. J Brit. Jour Surg., 21 38 No 81 July 1933)

Treatment. Complete surgical excision of the entire cyst and its wall and contents insures a cure.

Prognosis The prognosis for cure in these cases is good.

SEBACEOUS CYSTS

Sebaceous cysts may occur on the hand, but they are quite unusual They are limited in location to the dorsum of the hand and fingers as sebaceous glands do not occur in the palmar skin

The gross appearance and characteristics are the same for this cyst on the hand as elsewhere, and therefore a detailed description is not needed

MUCOUS CYSTS

Introduction and Historical. The original description of these interesting cutaneous cysts was given by Jones and Markins at the St Thomas Hospital in London. Since then they have been occasionally reported, but there is not a great deal of literature on them, as apparently they are so small and seemingly trivial They are frequently termed synovial lesions of the skin.

Etiology These cysts are believed to be due to mucoid degeneration in the cutis, possibly secondary to trauma.

Pathology Grossly these are small cysts in the skin filled with a colorless gelatinous viscid fluid not unlike that found in ganglia. Microscopically they are without epithelial lining, and there is no evidence of surrounding inflammation.

Incidence. Seventy five per cent of cases occur in adult females. As previously stated, they are probably much more common than they appear in the literature, as only 14 cases were reported up to 1937

Location. These cysts occur on the dorsum of any of the fingers, but the long finger seems favored They usually lie in the region of the distal joint, generally to one side of the midline.

Symptoms As they are small and occasionally tense they may become tender due to frequent trauma. As a rule, however, they are symptomless The patient ordinarily complains only of their presence.

FIG. 721 Mucous cysts. A skin tumor of typical location. Fairly good results from x ray, but curable by complete excision under tourniquet and covering over region by a skin flap. A thin skin graft is used to cover area from which skin flap is taken.

Diagnosis This is best made by their location on the dorsum of the distal segment of the fingers and by their superficial position in the skin.

Treatment. Recurrence after surgical removal is so frequent that x-ray therapy which cures the majority of cases has been advised as the method of choice. Surgical excision is, however, uniformly successful if it is complete. After the cyst is removed, the denuded area is covered by a split skin graft, or by the combination of local rotational flap and skin graft.

Prognosis. Good if surgical removal is complete

GANGLIA

Introduction and Historical. The word ganglion, aside from its use in connection with nervous tissue, is a term describing certain cystic tumors which may occur about the joints of the extremities, but most frequently about the wrist joint

There are many old discarded theories concerning the origin of a ganglion, and these are well outlined by Carp and Stout, who traced them from 1746 Some of these theories are as follows from tendon sheath retention-cyst tumors, serous cysts, *synovial* dermoids, arthrogenous blastemia and herniations of tendon sheaths and joints. Only since 1893 has the consensus of opinion been that ganglia arise from degeneration in the connective tissue outside of the joints, and this view is now generally accepted.

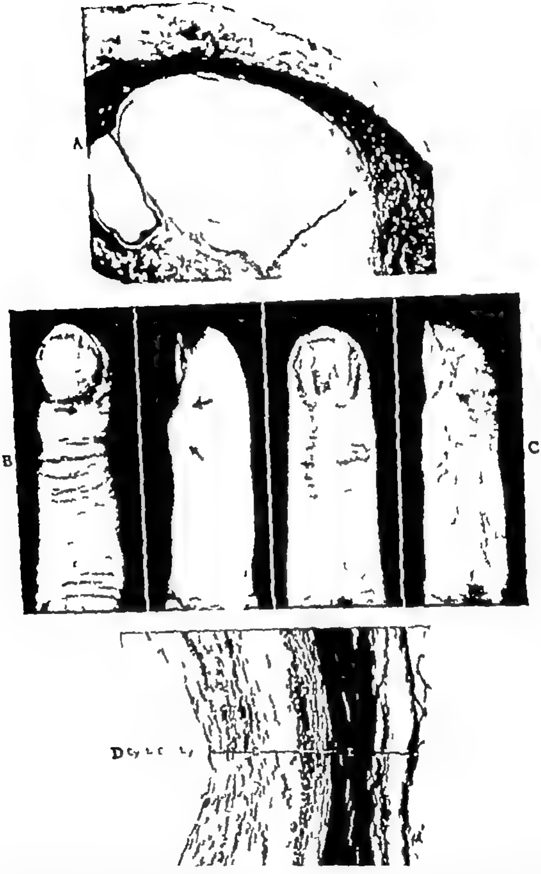


FIG 722 (A) Photomicrograph of myxomatous cyst. The cavity is formed by a myxomatous degeneration of the corium. The loose textured connective tissue of the cyst wall merges gradually into the normal derma as is seen in the right lower portion of the picture At the left, a down growth of the epidermal layer has surrounded a small part of the cyst. (× 20)

(B) Myxomatous cyst of left middle finger (C) same as (A) four months after x-ray treatments.

(D) Photomicrograph of roof of cyst. The epidermis E and the corium C, are essentially normal. The cyst cavity which was filled with mucoid material does not have any epithelial lining (× 125) (Courtesy Gross R. E. Surgery Gynecology and Obstetrics, 65,294–299 No 3 Sept., 1937)

FIG. 723 Ganglia.

FIG. 724 (A, *Top*) Ink outline of a non visible but palpable ganglion arising from the pulley opposite the proximal phalanx. Patient complained of local tenderness and pain on gripping.
(B *Bottom*) The removed specimen. Note the "brim" of ligamentous tissue excised with the ganglion The cyst measured 5 mm in diameter (Wakeman U S Army photo)

Etiology There has been much speculation as to just why ganglia arise One theory is that there is an *obliterative* endarteritis of traumatic origin as a result of which nutritional disturbances in the connective tissue occur, followed by degenerative changes, first several small cysts appear that later coalesce to form a large one Carp and Stout state that the origin of ganglia by direct trauma *is hard to understand* although a history of injury is given in approximately 50 per cent of cases. Falcom in 1908 believed ganglia came from the synovia and advanced three hypotheses *as to their origin first* that they were due to a sudden extrusion of synovial membrane through the joint capsule the narrow neck either remaining or becoming sealed off, second, that they result from fetal sequestration of synovial membrane and third that unobliterated synovial membrane became *separated as a result of inflammation* None of these hypotheses is accepted by present writers

Other theories advanced by Clark are that of specific degeneration of the connective tissue *secondary to poor nourishment*, and anatomic bursae which have become distended After detailed study, he concludes that it is connective-tissue degeneration

King suggested the origin of ganglia from a connective tissue proliferation with secretion *and formation of a pseudo joint cavity* as against the degeneration phenomena described by other authors.

In most reported series trauma appears to be a factor in from one third to one-half of the cases

Pathology The ganglia are structures *within the connective tissue* in close proximity to joints or tendon sheaths, or both, but

never communicate directly with the joints or tendon sheaths. There is generally one large cyst which may be unilocular or multilocular and about this cyst, at its base, numerous accessory cavities or small cysts are found All of the cysts are composed of a dense, fibrous connective tissue wall without any special type of lining cell The contents are generally colorless and of a thick, sticky consistency resembling a soft jelly On section, in the cyst wall and in the connective tissue about the cyst can be seen areas of degeneration where the connective-tissue fibers become stringy and spread apart and the cells vacuolated There is no microscopic evidence of inflammation, only a few monocytes being seen in the vicinity In some instances nerves have been observed, such as the twigs of the sensory radial passing directly through a cyst structure.

Ganglia never become malignant and they are not known to rupture through the skin

Incidence. Occurring at any age, most cases are seen between the ages of 15 and 50 They are more common in females than males, and occupation seems to have no particular bearing on the incidence

Location In the upper extremity ganglia are most frequently found about the wrist and on the volar surface of the palm and fingers About the wrist they invariably arise from the joint capsule and most commonly over the dorsal aspect of the navicular lunate articulation, where, as they become visible tumors, they are bounded by the long extensor tendon of the thumb and those of the fingers

The commonest site on the volar surface of the wrist is between the tendons of the flexor carpi radialis and the brachioradialis. Commonly in the hand they arise in the deep pulleys overlying the long flexor tendons near the metacarpal heads and sometimes opposite the middle of the proximal phalanx They may also occur on the dorsum of any interphalangeal joint.

Symptoms Most symptoms of ganglia are due to the presence of the local swelling Weakness of the hand or joint may be complained of, and in half the cases a mild

FIG. 725 (*Left*) Lower power photomicrograph of a ganglion. Above is the multicystic cavity surrounded by its dense fibrous wall with remnants of incomplete septa projecting into it. To the right is an accessory cyst cavity Below it an extensive area of mucinous degeneration with many tiny cavities scattered through it.

(*Right*) A high-power photomicrograph showing some cells in an area of degeneration distended with vacuoles containing mucin. (Courtesy Stout and Carp Surgery, Gynecology and Obstetrics, 47 465 1928)

neuralgic pain. The swelling may appear gradually or is noticed suddenly The ganglion varies from small size to 6 cm. in diameter In the palm or proximal finger segments there may be tenderness when objects are grasped Ganglia are not known to have any definite function and do not themselves become the seat of disease, in contrast to bursae which may become secondarily involved

Diagnosis These tumors are readily recognized when they occur about the wrist, and a definite diagnosis can be made by aspiration, though this is rarely necessary *The differential diagnosis includes* lipoma, xanthoma, inclusion cysts, and tuberculous tenosynovitis, all of which are usually less tense than a ganglion.

The smaller deep ganglia of the palm and fingers are more difficult to palpate and are tense and hard, being readily confused with fibroma.

Treatment. The treatment of ganglia may be divided into operative and nonoperative methods In the latter category it must be mentioned that occasionally ganglia disappear of their own accord, probably as a result of spontaneous rupture. The other nonoperative methods of treatment may be listed as follows

Rupture by External Force. This method will succeed in a few cases, but has generally been tried before the patient is seen by the physician. Recurrence is common, and it is probable that the trauma may initiate formation of other new ganglia at the site.

Aspiration of the Contents with Injection of Sclerosing Agents or Application of Pressure. This method is a favored one used in hopes of avoiding an operation It gives a low percentage of cures and is accompanied by some danger Sclerosing solutions such as iodine, carbolic acid, sodium morrhuate, etc., have been used. In 1940 Ball advocated the use of the proteolytic enzyme caroid but this was condemned by Key in 1942 following an unsuccessful trial Kaplan reports good results in using 5 per cent sodium morrhuate and a compression dressing, but admits several treatments are often necessary

Treatment by Roentgen Therapy Considerable success is attributed to this method by Lyle in reporting 21 cases so treated. Of these 17 cases were considered good results He was able to cause disappearance of the tumor in 81 per cent of the cases, relief of pain in 78 per cent, and relief of weakness in 82 per cent. The *method consists of giving 1 5 erythema dose* over the tumor and repeating in one month. *If additional* treatments are needed they must be scheduled by the roentgenologist to avoid damaging effects of radiation on the skin. The method has many advantages, including less expense, no loss of time, no operation or hospital stay, and no resulting scar

Physiotherapy This possibility in treatment is mentioned only to state that it is not of value and should not be used

Surgical Excision Most authors agree that operative treatment offers the best chance of cure. Recurrences by this method do occur and are reported variously from 15 to 33 per cent Neumuller and Urapor, reporting on 702 cases, state that one third *recur after surgery* and two-thirds following other methods.

In the series of Bunnell which I tabulated the percentage of recurrence was very low, and to insure this result certain operative precautions should be taken These consist of operating in a bloodless field by use of a tourniquet and meticulous dissection of the entire ganglion, including extirpation of the ligamentous structure from which the ganglion arises so that small adjacent cysts *and ganglion-producing* tissue will be included.

Prognosis. The prognosis for the condition in general is good since ganglia have never been known to do real harm or to become malignant. The prognosis for cure depends on the method of treatment and is

best when careful, adequate surgery is per formed.

Summary of Case Histories of Bunnell. GANGLIA AT WRIST There were 44 cases of ganglia at the wrist. Of this number 19 were in males and 25 in females. The average age was 30½ years, the oldest case being 59 the youngest 15 The locations of the ganglion (specified in 38 cases) were on the dorsoradial aspect in 18, on the dorso-ulnar aspect in one, and in the mid-dorsal region in 10 On the volar radial aspect there were 9 cases and none on the midvolar or ulnar volar aspect.

They were found equally on the right and left side. The presence of multiple ganglia was noted in only one case, in which there were two—one on the right wrist and one on the left wrist. The occupation of the individual seems to have no particular bearing on presence or absence of ganglia. The origin of the wrist ganglia in all cases was noted to be from the capsule of the wrist joint.

The commonest complaints were pain, aching and weakness. These were in addition to the complaint of the cosmetic appearance of un sightly lumps on the extremity The symptoms varied from one week to 15 years duration, and notice of the tumor 3 days to 50 years. In 33 cases the tumor had been present less than a year in 13 cases the average duration was 2 8 months. The swelling had been present over a year in 20 cases with an average duration of 8 years. In 5 cases the tumor had been present over 10 years with an average duration of 22 years. In 15 cases the tumor had been there over one and under 10 years with an average duration of 4 years.

The presence or absence of trauma was noted in 34 of the recorded cases, trauma seeming to play a role in 13 of these and not in 21 Ten had been operated on previously 4 once 4 twice one 3 times and one 6 times. These ganglia had recurred at time intervals varying from 2 weeks to 10 years. Certainly in the lat ter instances it is most probable that a new ganglion developed In all these cases excision was carried out through a transverse incision under the ischemia of a tourniquet and in most under local anesthesia. A plaster splint for two weeks lessened pain and promoted healing. In all cases the ganglia were found to arise from the capsule of the wrist joint and in each instance the capsule at the site of origin was excised much like the brim of a hat. None recurred.

GANGLIA ELSEWHERE THAN AT WRIST Of 9 cases, in 4 the ganglia were in the fingers, 4 in the palm, and in one case one and one half inches

FIG. 726 (A, *Top*) Ossifying fibroma on the dorsum of the wrist simulating a *ganglion*

(B *Bottom*) Removed specimen which on microscopic examination showed abundant bone formation (Wakeman U S Army photo)

above the wrist arising from the sheath of the abductor pollicis longus. Of those in the fingers one was volar-radial from the annular ligament in the proximal segment of the little finger but the others were dorsoradial in the proximal seg ment—one in the little finger one in the index finger and in one case bilateral in both ring fingers. Of those in the palm 2 on the left and 2 on the right, 3 were opposite the base of the long finger and one opposite that of the ring finger All arose from the volar aspect of the annular ligamentous tendon pulley opposite the metacarpal head

These ganglia were 3 to 10 mm. in size, having been present from 2 to 6 years. Five were in females and 4 in males. The only symptom was tenderness. One recurred, necessitating a second removal, which was successful. The same principles of excision were carried out namely ex cavation of the ganglion sac in its entirety in cluding the surrounding brim of ligamentous tissue.

FIBROMAS

Introduction and Historical These tumors are in general common over the body but are not very frequent in the hand They may occur at almost any site, in the superficial or deep structures. They are benign and as a rule slow-growing.

Etiology The etiology is unknown.

Pathology The gross appearance of these tumors varies as to their location and size. They tend to be roughly spherical in shape and are firm with an elastic resilience. The microscopic picture is that of dense fibrous connective tissue in sheets or whorls At times calcification or even cartilage and bone formation may occur

Incidence The specific incidence of these tumors of the hand cannot be ascertained from the literature.

Location. Fibromata may occur in the skin or subcutaneous tissue or be connected with the deeper fascia or ligaments of the hand. They have been described as tumors of the tendon sheaths, and also of the tendon proper in rare instances. Fibrous nodules are occasionally seen over the dorsum of the middle joints of all fingers, excluding the thumb These are called Garrod's pads are believed hereditable, and may represent an atavistic character In the tendons, they may lead to snapping finger as the presence of the lesion increases the diameter of the tendon, producing the phenomenon as this area travels past the relative constriction of a pulley Occasionally a fibroma may be subungual in location, and while they are not painful at this site due to their slow growth, they cause distortion of the nail and pressure atrophy of the distal phalanx. Levinthal and Kirschbaum report a case of a large fibroma of a metacarpal bone, but there is some question regarding the pathological classification in that it could be regarded as an extreme case of a sclerosing type of giant cell tumor

FIG. 727 (A, *Left*) Large subungual fibroma of six years duration. Deformity of nail, displacement of finger pulp, and erosion of distal phalanx made amputation through base of distal phalanx necessary
(B *Right*) X ray showing erosion of distal phalanx. (Wakeman U S. Army photo)

Symptoms. Fibromata are as a rule symptomless unless their location and size are such as to interfere with function or to press against nerves.

Diagnosis. *The diagnosis of fibroma is* generally made on the firmness of the tumor Fibroma of the skin may be confused with neurogenous tumors The deeper seated fibromata offer a more difficult diagnostic problem in that they may be confused with ganglia, epidermoid cysts, and other firm lesions.

Treatment. The treatment of a fibroma is surgical excision, and this usually can be readily accomplished

Prognosis Prognosis for cure is good, as the tumors are benign in type.

LIPOMAS

Introduction and Historical The soft lipomas which occur mainly in the subcutaneous areas over the body are well known by the clinician, and as a rule are easily diagnosed. Occasionally they may occur in the hand, but in this locality they are infrequent and the diagnosis is often mistaken.

Etiology The etiology of the lipoma is not known.

Pathology On gross appearance these *tumors are soft masses, generally lobulated,* surrounded by thin but definite capsules. The miroscopic picture varies somewhat, depending upon the amount of fibrous tissue associated with the fat. Some myxomatous tissue may also be present.

Incidence Lipomas have been stated to be more frequent in males than in females, and while usually single they may be multiple

Location. Lipomas have been described in various locations on the hand Those which involve the tendon sheaths, as simple tumors or arborizing masses, are considered by some authors to be basically synoviomas of the lipoid type. Other lipomas occurring outside the tendon sheaths may be superficial as found elsewhere in the body, or they may originate deep in the hand, usually in the palm At this site they become so bounded by the various ligaments, fascia, and tendons that they take unusual form, insinuating themselves in the fascial planes and often presenting superficially in the distal palm or following the interosseus tendons to appear on the dorsum between the fingers. In general they occur more frequently on the volar surface of the hand than on the dorsum

Symptoms. The symptoms presented by lipoma in the hand are generaly mechanical ones as a result of the size of the lesion.

Diagnosis. These lesions are often not diagnosed before operation, yet they have some characteristics which should lead to

FIG 728 Lipoma growing in palm for 13 years.

FIG. 729 (*Left*) Small lump present in palm four years which proved to be a nodule on an extensive lipoma that filled the thenar and palmar spaces. (*Right*) Tumor laid on a hand to show location.

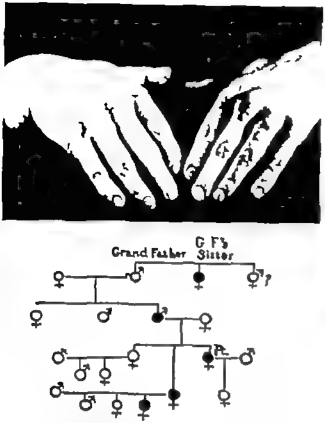


FIG 730 (*Top*) Xanthomata, multiple over body hereditary born with tumors over proximal finger joints increased in adolescence

(*Bottom*) Genealogy of patient.

FIG. 731 Seven months ago a month after striking long finger with a hammer the tumor appeared which now shows as a bulge in finger and palm.

Insert shows xanthoma excised. It grew from the annular ligament in the palm, extending down the tendon sheath to form a second nodule in the finger

early recognition Because they are soft and flabby in structure they give a suggestion of fluctuation on physical examination It has also been reported that the application of an ice bag over the tumor leads to an increase in the firmness as a result of chilling of the fat. The differential diagnosis includes *hemangioma*, *synovioma*, *xanthoma*, and other soft lesions.

Treatment. The treatment is surgical removal of the tumor, and in so doing it is necessary to remove the lesion completely to avoid recurrence. This is best done under the ischemia of a tourniquet, as perfect vision is essential.

Prognosis. The prognosis for cure is good

XANTHOMAS OR XANTHOMATIC TUMORS

Introduction and Historical This tumor is of unusual interest, not only because of its frequent occurrence in the hand, where it appears in a diversity of forms, but also because of its obscure etiology and its relationship to the physiology of fat metabolism within the body The latter subject is extremely interesting and complex but cannot be considered in detail at the present time. For all practical purposes, most xanthic tumors of the hand can be considered and treated as local entities. Those occurring in the bones of the hands will be considered under the heading of Bone Tumors.

Xanthomas have been described in medical literature since 1836 but the first reference to xanthoma of a tendon sheath of a finger was by Chassaignac in 1852 Other descriptions soon followed, but considerable confusion existed as to the exact nature of the lesion. Heautaux in 1891 was the first to separate these tumors from sarcomas and Dor in 1898 was the first to describe a xanthoma cell and suggest an inflammatory origin of the condition After 1900, with the numerous cases being reported, confusion in nomenclature became apparent. Such terms as giant-cell sarcoma,

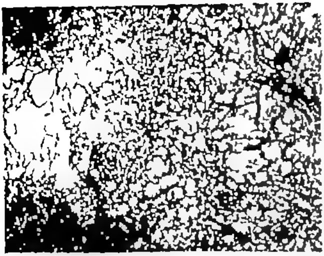


Fig. 732 Xanthoma showing large numbers of foam cells in the right side of section and cholesterol clefts in the left side. Fibrous and cellular stroma and several foreign body giant cells are present. (× 60) (Courtesy Galloway J D B A. C. Broders, and R. K. Ghormley Arch. Surg. 40 516 No 3 March, 1940)

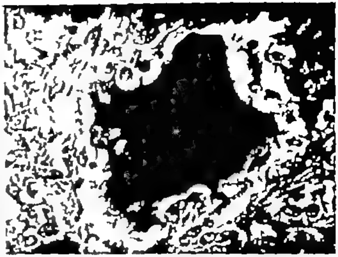


Fig. 733 Xanthoma showing the shape and structure of a foreign body giant cell with characteristic cytoplasm and many endothelium-like nuclei The surrounding tissue shows typical endothelium like stroma cells with their pale staining nuclei and prominent nuclei. (× 440) (Courtesy Galloway J D B A. C Broders and R K Ghormley Arch. Surg., 40 516 No 3 March, 1940)

Fig. 734 Xanthoma tuberosum. (Courtesy Miller Carl Arch. Int. Med., 64 680 1939)

myeloid endothelioma, granuloma, xanthosarcoma, giant-cell tumor, etc., appeared

Etiology The origin of the xanthoma is not as yet definitely known As previously stated, Dor was first to suggest an inflammatory origin, and Weber in 1924 was the first to associate xanthic tumors with what he termed cholesterin diathesis and that opened up a large field for speculation and study The local origin of xanthomas from sesamoid bones was presented by Geschickter and Copeland, in 1929, but this has not been confirmed by other authors. That xanthomas are true neoplasms of mesothelial origin and do not result from inflammation or altered lipoid metabolism was advocated by Ragins in 1931 Trauma is frequently suggested as an inciting factor due to the high incidence of these tumors on the fingers and hands Mason and Woolston, in their study of isolated soft tissue xanthomas report that five out of eight cases give a definite history of trauma. Other authors believe that some disturbance in lipoid metabolism is a preexisting condition and possibly a primary factor, as in some reports as high as 50 per cent of cases show some disturbance in the cholesterol ester ratio It has been pointed out that perhaps both factors are necessary, and if trauma is added to a preexisting alteration of lipoid metabolism, the blood and fat liberated set up a secondary response in the tissues resulting in a xanthic tumor

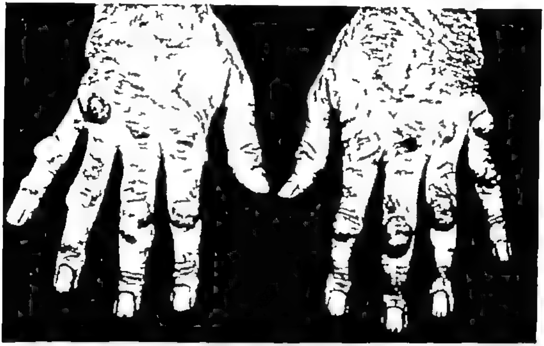


FIG. 735 Multiple xanthomas of hands and feet. (Xanthoma tuberosum multiplex.) This condition may be related to a lipoid diathesis, as there is often an increase in the total lipoids, cholesterol, and cholesterol esters in the blood stream. (Courtesy Pack, G T Tumors of the Hands and Feet, St. Louis, The C. V Mosby Co 1939)

Pathology The lesion is a benign growth, which on gross examination may be round, ovoid, or lobulated, and of variable size. It is generally encapsulated, moderate to firm in consistency, and grayish yellow, yellow brown or even a red brown in color The pigment may not be uniformly distributed, but may appear as streaks or areas The microscopic picture shows much variation in the number and type of cells present, but after careful study certain characteristic features are always found. Foam cells exist in variable numbers, from a few to so many that they appear to make up the entire bulk of the tumor They are quite characteristic and are always

described in connection with xanthoma. The nuclei of these cells are small, the cytoplasm granular and foamy due to lipoid globules. These cells are believed to be histiocytes which arise from the reticulo-endothelial system The yellow color of the tumor is due to carotene and xanthophyll pigment in the contained lipoid globules. Cholesterol crystals have also been observed within these cells Foreign body giant cells are present in variable numbers. These cells are large, and have their origin in fusion of endothelial cells They behave in a phagocytic manner as they pick up fat and pigment. The stroma cell or type cell is more or less spindle-shaped, resembling an endothelial cell. The nuclei are ovoid, and mitoses are rare. In addition to these cells some free fat and hemosiderin pigment may be present other than intracellular in location. Scattered small hemorrhages may occur throughout the tumor and are quite characteristic. It is probably from these that the hemosiderin pigment arises Ordinary fibrous connective tissue is also present in various amounts in strands throughout the tumor

Incidence Xanthomas are among the more common tumors encountered in the hand. They may arise in any of the tissues, but are most commonly subcutaneous There is equal distribution between the sexes, and occupation or heredity are not as a rule considered factors in their appearance. They present themselves primarily in the middle age group but may occur at any age.

Location. As previously stated, they may make their appearance in almost any tissue of the hand They occur in the skin or as isolated tumors in the other soft tissues. They may be present in the bone or they may arise from deep ligamentous structures or within tendon sheaths. They appear with twice the frequency on the right hand as on the left, and are most common on the index finger, then the thumb, long, little, and palm and ring finger, respectively After incomplete surgery they may be found disseminated throughout the immediate soft tissues In the literature, lesions on the dorsum of the hands and fingers are frequently termed "xanthoma tuberosum"

Symptoms. Since xanthomas are painless slow growing tumors they do not as a rule give rise to much in the way of symptoms until they reach a size which interferes with the function of the hand or its cosmetic appearance. The most frequent complaint given by patients is the mere presence of the tumor

Diagnosis. Since a xanthoma is one of the most common tumors of the finger and the most frequent tumor of the tendon sheath, the diagnosis as a rule does not present a difficult problem The tumor is usually solitary and most often on the flexor surface. The blood cholesterol ester ratio is not usually of value in the diagnosis Differential diagnosis would include lipoma, chondroma, and angioma. Large, gouty tumors which may occur and appear yellow when they are close under the skin may be included in the differential diagnosis Ganglion may also be considered, and when the tumor is within the tendon sheath, differential diagnosis between xanthoma and tuberculous infection presents a possibility

Treatment. Local surgical excision of the tumor generally suffices for a cure. Recurrences may appear, but these generally can be again handled by local excision In one instance, recurrence throughout the soft tissues of a finger was so extensive that the possibility of removing all of the tumor and still saving the finger was out of the question, and amputation was necessary The use of roentgen therapy is of questionable value, although adequate statistics for other than the bone xanthomas are not available for study In the surgical treatment, the operation should be performed under the ischemia of a tourniquet so that all of the tumor tissue can be seen and removed with

out damage to other important anatomic structures.

Prognosis The prognosis is generally favorable for cure, although the rate of recurrence in cases treated surgically is estimated at approximately 10 per cent. The lesion is benign and should be so treated

FIG. 736 (*Top*) Photomicrograph of a section of a synovioma removed from the thumb The tissue lining the space resembles that of synovial membrane, and is of the fibrous type. (× 80)
(*Bottom*) Photomicrograph of another portion of the growth shown in the top illustration. Giant cells and foam cells are present. (× 80) (Courtesy King E. S J Brit. Jour Surg., 18 599 No 72 1931)

TENDON-SHEATH TUMORS

Introduction and Historical The continuous synovial lining was first described by Bonn in 1763, but its exact nature was not clarified until Heuter in 1866 and Lubasch in 1910 advanced the view that the synovial membrane was not an epithelial lined structure, but rather a specialized connective-tissue surface. This structure lines all open joints, with the exception of the articular surfaces, and forms the lining of tendon sheaths Tumors may arise from the synovia and these tumors therefore occur in the joints and the sheaths. The hand is abundantly supplied with both, but singularly enough the tumors are practically entirely limited to the sheaths, where a great variety of them occur, both benign and malignant.

Much confusion is apparent in the literature as to the nature of these tumors. King makes an attempt to clarify the subject by stressing the fact that most authors try to classify the tumor by the predominating cell, when in reality—since these tumors all arise from the synovia—the basic cell is the same and their variable gross and microscopic appearance is due to predominating *cell structures closely associated* with the tissues underlying the true synovial covering. Thus, such terms as angioma, arborizing lipoma, *endothelioma*, *myeloma*, fibroma, chondroma, etc., of the tendon sheaths appear in the literature.

The *synovial cell* is a *modified* connective tissue cell of mesodermal origin and is spindle or spheroidal in shape In certain instances transition to cartilage cells or even bone cells is not an uncommon finding and evidences its potentialities Projections of synovial membrane, as a result of inflammation or infection, occur to form villi in tendon sheaths. These villi are covered by synovial cells but their internal structure

takes on the character of the underlying tissues in that region When tumors form, the type cell of the synovia is always present, and within the tumor spaces appear which are synovial-lined The outward appearance varies as to the other cells present, accounting for the wide diversity of forms. The term 'sarcoma" is properly applied to the malignant form of the tumor, in view of the cell origin

Haagensen and Stout have recently reported on synovial sarcoma, and their series contains three of the hand, four of the fingers, and four about the wrist. They state that this malignant tumor is slightly more common in males than in females and usually occurs in early adult life Pain is an early symptom in contrast to the benign form and while the early course of the disease may be chronic, metastasis occurs sooner or later through the blood and lymph stream.

Etiology The origin of tendon-sheath tumors is unknown Trauma is frequently mentioned as a factor, as it may occur in the clinical history and for some authors explains the presence of the xanthoma cell. Chronic synovitis of traumatic or low-grade infectious origin must also be considered as a possible etiologic agent.

Pathology The pathology of synoviomas is characterized by the diversity of cell forms, and many sections through the tumor are needed to show all types of cells present. The synovial type cell is always present and spaces in the tumor so lined can generally be found. In addition, there may be fibrous tissue, cartilage, foam cells, giant cells, and fatty tissue which appear in variable amounts and arrangement with one or the other type cell predominating, leading to a specific naming for that particular tumor The giant cells of foreign body type and the foam cells characteristic of the xanthoma may be present in abundance and are almost always present in some degree The xanthomas of the tendon sheaths, which have been separately described, probably represent one variant of this group In the malignant forms of the synovioma, the spindle-like cells are densely packed and have round or ovoid nuclei with numerous mitotic figures In gross appearance the tumors are generally soft and lobulated, extending a variable distance up and down the sheath and may become adherent at numerous points. Be

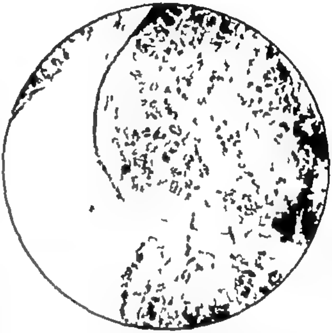


FIG. 737 Chondroma of tendon sheath. (× 85) (Courtesy Buxton St. J D Brit. Jour Surg., 10 471 No. 40 1923)

nign forms do not show the invasive tendency of the malignant variety In color the tumors are most commonly grayish white, or with a light to dark yellowish tint if fat or xanthoma cells predominate.

Incidence Synoviomas may occur at almost any age, but most become manifest in the third and fourth decades.

Location. There are incomplete statistics on those occurring only in the hand but they may involve either the volar or dorsal aspects.

Symptoms As these are slow growing tumors as a rule, they do not give rise to much in the way of symptoms until they have become of considerable size. They may then interfere with motion of the extremity, or appear as visible swellings on the hand.

Diagnosis. The diagnosis is difficult, but at times can be made on the physical examination The tumor may follow along the course of one of the tendons for a variable distance, or it may remain localized. Some interference with function may be present.

Treatment. The benign forms of synovioma can be removed locally with good results if a careful and complete operation is performed. Like other tumors, they are prone to recur In the malignant forms early amputation is advisable at a site best judged by the surgeon at the time.

Prognosis. The prognosis is good for the benign forms, but the malignant synoviomas tend to recur locally and metastasize readily to the regional lymphatics.

PERIPHERAL-NERVE TUMORS

Under the heading of peripheral nerve tumors come a variety of new growths of controversial origin and classification

The best approach to a study of these tumors is a knowledge of the histologic elements of a peripheral nerve in the hand, with recognition of the fact that tumors may arise from each or combinations thereof Present in a peripheral nerve is the neuraxon, which may give rise to fibrillary neuromas, and the sheath structures including that of Schwann and the connective-tissue endoneurium, which may give rise to several types of new growths classed as tumors of the nerve sheath. In addition to the nerve fibers and their sheaths specialized end organs of nerves are present, and tumors arising or believed to arise therefrom are also classed as nerve tumors.

Some authors include in this group the *glomus tumor*, *melanosarcoma* or *carcinoma*, some types of xanthoma, and the leiomyoma, but these are given consideration elsewhere in this treatise.

Fibrillary Neuromas

The most commonly encountered neuroma in the hand is that resulting from traumatic injury or severance of a peripheral nerve This tangle of neuraxons and sheath cells is termed by Foot a false fibrillary neuroma, as he states some authors are hesitant about classifying these with true tumors. They result from the effort of the severed nerve to rejoin

Fig. 738. A fibrillary neuroma terminates each volar digital nerve and has grown into the scar of the amputation stump producing a visible tumor (Wakeman U S Army photo)

The etiology is always clear, as there is a history of injury which involves one or more of the peripheral nerves. The gross pathologic picture is a bulbous termination of the proximal end of a severed nerve, or a bulbous enlargement of a nerve at the point of injury These tumors are encapsulated unless they are buried in dense scar Microscopically all elements of the nerve are seen in one tangled mass.

These neuromata are limited in their location as they must be along the course of the nerves, and therefore occur largely in the palm and on the volar surfaces of the fingers.

The symptoms are tenderness and pain, the latter being shock like or burning in nature and referred over the course of the sensory distribution of the nerve *Small neuromata of the sensory branches of the radial nerve in the hand are particularly bothersome.*

The diagnosis of these traumatic neuromata is based on the history, the local signs of neuroma including often the palpable tumor and the area of disturbed cutaneous sensation Treatment is discussed elsewhere under nerve suture, but when this cannot be accomplished—as in amputation stumps—resection of the neuroma with treatment of the nerve end is advisable (p 375) The prognosis in general is good, although some cases prove refractory

True fibrillary neuromata are rare, but have been described as enlargements in ex cess to need of peripheral nerves They may be localized areas in a nerve or form plexiform structures. When they involve the deeper nerves they are sometimes associated with localized hypertrophy of a part (elephantiasis nervorum)

FIG. 739 (A, *Left*) Ink outline of palpable but not visible tumor overlying the deep carpal ligament. The tumor is firm, round, and slightly tender on pressure.

(B *Below*) Same tumor at operation showing its origin from palmar branch of median nerve. Microscopic study showed proliferating nerve sheath cells and myxomatous connective tissue surrounded by a well developed fibrous capsule. The diagnosis is neurilemmoma (benign nerve sheath tumor) (Wakeman U S Army photos.)

While generally considered to be congenital in origin, unrecognized trauma may play a rôle in the more superficial ones. Treatment of a surgical nature is carried out only when indicated.

Nerve sheath Tumors

In this group are numerous, small, usually benign tumors which occur not infrequently in the hand. Whether they arise from the sheath cells of Schwann or from the endoneurium is of little importance, but it is of course necessary to recognize any malignant tendency

Various classifications of these tumors have been suggested but they cannot always be followed histologically or clinically Geschickter advises that they be grouped on the basis of their differentiation and this method is as practical as any

The well-differentiated forms show histologically varying degrees of fibrosis, and the type cell has a small nucleus with peripherally located chromatin, the cytoplasm being abundant and syncytial They are well encapsulated and generally occur on the flexor surface of the upper extremity in the subcutaneous tissue, where they are attached to a peripheral nerve branch, often in the vicinity of a flexion crease. Most cases appear in the age period of 30 to 50 years. They are usually symptomless and do not often become malignant, so that they are readily cured by surgical removal. The term neurilemmoma has been suggested for them.

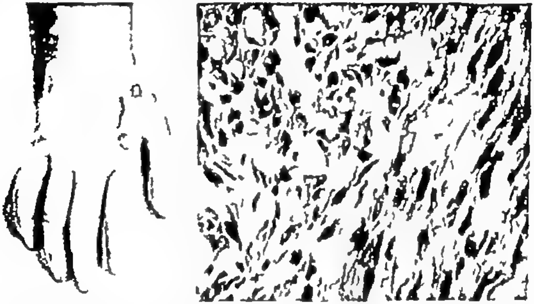


Fig. 740 Peripheral nerve tumor Photograph and photomicrograph of a subepidermal spindle-cell sarcoma of the nerve sheath recurrent after excision and irradiation.

The characteristic cells of Schwann are shown in the photomicrograph, with large amount of collagen. (Courtesy Geschickter C. F Amer Jour Cancer 25.391 1935)

The less differentiated forms, characterized histologically by a loose reticular structure, spindle cells, and considerable myxomatous tissue, are not encapsulated and occur most frequently in the subepidermis or deep along the main nerve trunks.

The subepidermal type are quite common and may be multiple. They are variable in form and appearance, and removal of some of the types is often sought because they may be blemishes. In general they are called neurofibroma and include the multiple neurofibromata of von Recklinghausen

The more deeply situated tumors are present along nerve trunks and involve the nerve to varying degrees. They are poorly

FIG. 741 Tumor of the right thumb probably attached to a digital branch of the radial nerve. Present for 12 years in a woman 28 years old. (Courtesy Stout A. P Amer Jour Cancer 24 755 August, 1935)

FIG. 742 Tumor nerve sheath of right palm attached to probably a branch of n. cutaneous antibrachii lateralis. Present for 20 years in a woman 53 years old (Courtesy Stout, A. P *op cit*)

demarcated from the surrounding structure, grow fast, and are prone to recurrence and malignant degeneration. In contrast to the well-differentiated types they may occur in young individuals.

In the series reported by Geschickter 30 per cent recurred, and of these one-half became malignant. Fortunately they do not occur frequently in the hand

Neurogenous sarcoma may arise from any of the nerve-sheath tumors, but most frequently develop in the poorly differentiated types. Histologically they show bundles of interlacing plump spindle cells

with frequent mitoses and tumor giant cells. They are highly malignant and invasive, extending up and down the course of the nerve. They are prone to occur in the third and fourth decades, and satisfactory treatment means prompt and radical amputation. In von Recklinghausen's disease it has been reported that in 13 per cent of the cases one or more of the tumors undergo malignant degeneration

The differential diagnosis of all forms of nerve-sheath tumors necessitates consideration of many other varieties of tumors. The superficial ones may be confused with fibroma or lipoma while the deeper ones may resemble ganglion, xanthoma, synovioma, and others. In general the incidence of correct preoperative diagnosis is low

TUMORS OF BLOOD AND LYMPH VESSELS

Aneurysm Traumatic

Introduction and Historical. Traumatic aneurysms may appear in the hand, and in view of the frequent injury to this area of the body it is surprising that more of them do not occur

Etiology Aneurysms in the hand which result from trauma generally follow a blunt force which weakens the arterial wall or actually ruptures it in one place. They may follow a penetrating wound which perforates an artery, and the incidence of this type is naturally increased as a result of war wounds

Pathology Traumatic aneurysms are divided into the true type, consisting of uniform dilatation of the vessel, but this form is rare. When it does occur, it is generally due to prolonged, frequent, recurring minor trauma. In one such case in the literature the lesion appeared in a soldier and was attributed to the repeated blows of the bolt of a gun. These aneurysms on examination show uniform dilatation or saccular extension in which the wall of the vessel is thin but intact. Mural thrombi are present. The other type, false aneurysm, is more common. It varies in size from a few millimeters to several centimeters, and is the result of the disruption of the wall of the vessel and the formation of a hematoma which becomes surrounded by fibrous connective tissue to form a false sac. Although these aneurysms tend to increase gradually in size, the amount of scar about them as a result of the trauma may prevent them from doing so

Incidence The traumatic aneurysm is the most common one encountered in the hand and is naturally found most frequently in individuals whose hands are subjected to occupational hazards.

Location. The superficial palmar arch is the most frequent site, being in approximately a 6 to 1 ratio with the deep arch Another common location is in the anatomic snuffbox where a branch of the radial artery is involved.

Symptoms These generally do not develop until some time has elapsed after the injury A pulsating tumor may then appear, which gradually increases in size.

Diagnosis. This can usually be made clinically by the presence of the pulsation.

Treatment. Treatment consists of excision as anastomosis is adequate.

Prognosis. The prognosis for cure is excellent.

Aneurysm Arteriovenous

Introduction and Historical. The presence of arteriovenous communications in the hand, short of the capillary bed, is well recognized as normal anatomy in the neuromyo-arterial glomus. In this instance, however, the blood flow between the two systems is controlled by a physiologic mechanism Other arteriovenous communications in the hand may occur, either singly or in numbers, and independently or associated with vessel type angiomas. Except in rare instances, these abnormal com

munications can be considered congenital in origin. Although arteriovenous aneurysms have been recorded in the literature for a long time, the first known case having been presented by William Hunter before the Medical Society in London in 1757, most of the interest in them has been due to their profound effect on the circulatory system of the entire body Small peripheral communications, however, have mainly local manifestations and, therefore, have not attracted as much attention from investigators Dean Lewis in 1930 reported nine cases of congenital arteriovenous aneurysms, one of which occurred in the hand

Etiology While these aneurysms are conceded to be congenital in origin, they do not necessarily manifest their presence

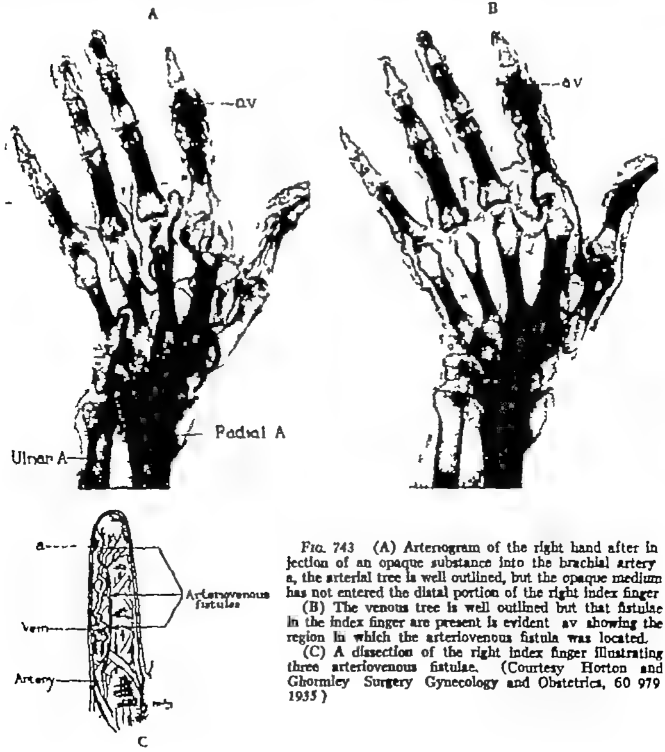


FIG. 743 (A) Arteriogram of the right hand after injection of an opaque substance into the brachial artery a, the arterial tree is well outlined, but the opaque medium has not entered the distal portion of the right index finger

(B) The venous tree is well outlined but that fistulae in the index finger are present is evident av showing the region in which the arteriovenous fistula was located.

(C) A dissection of the right index finger illustrating three arteriovenous fistulae. (Courtesy Horton and Ghormley Surgery Gynecology and Obstetrics, 60 979 1935)

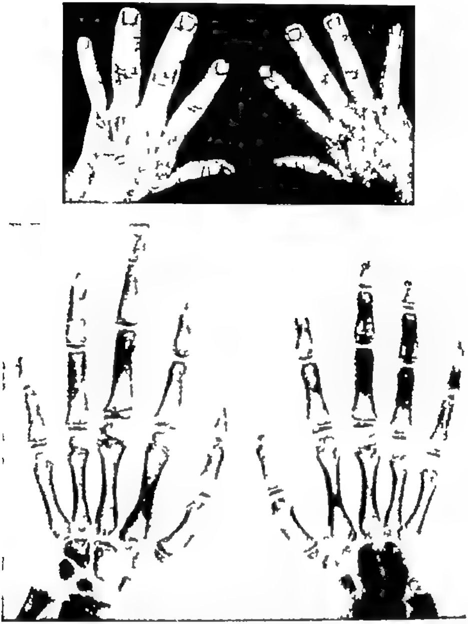


FIG. 744 (*Top*) Arteriovenous aneurysm of superficial and deep palmar arch, with marked hypertrophy of third and fourth fingers.
(*Bottom*) Arteriovenous aneurysm of superficial and deep palmar arch, showing overgrowth of phalanges of second third, and fourth fingers. (Courtesy David V C. Arch. Surg., 33.269 August, 1936)

at birth, but may become evident later in life. It may also be true that arteriovenous communications can develop postnatally in the vessel type angioma. The best evidence for the congenital origin of this lesion is the frequency with which multiple communications are present, as many as 30 having been reported in one case in an extremity

Pathology The pathology of the congenital arteriovenous aneurysms is mainly in the effects they produce locally In the young this may amount to a hypertrophy of the affected part as a result of the increased blood flow This phenomenon is seen in individuals under 20, as it apparently does not occur later in life when the epiphyses have fused.

Incidence. No definite figures as to sex, occupation, racial distribution, etc., could be found They are seen primarily in young individuals between the ages of 7 and 20, as might be expected.

Location. These aneurysms are mainly in the palm, involving either the superficial

or deep palmar arch. They may also occur in the fingers and are often multiple in this location.

Symptoms. The symptoms are referable in general to the increase in circulation of the part, and consist of an increase in local heat and sweating, and often the presence of pulsation Pain is not a common symptom. Large communications may result in limited blood supply distally, and in such an instance there may be a drop in temperature, cyanosis, and even gangrene

Diagnosis. Diagnosis is made on the local manifestation of the arteriovenous aneurysm, as the cardiovascular phenomena—commonly associated with larger lesions elsewhere—are as a rule absent. There is usually local swelling and pulsation with enlarged veins on the dorsum of the hand. Not infrequently, the typical machinery type murmur can be heard on ausculation In the congenital type there is, of course no history of injury Other aids in establishing a diagnosis are arteriography and oxygen determination of venous blood Arteriography may prove helpful, prior to surgery, by showing the number and sites of the communications.

Treatment. The same principles of treating arteriovenous fistulae elsewhere in the body apply here, and cure is dependent upon complete excision of all the communications.

Prognosis. In most instances arteriovenous communications can be eradicated but, of course, one cannot expect regression of already hypertrophied parts. Occasionally amputation may have to be resorted to in the event of insufficient circulation following eradication of the fistulae.

Angioma

Introduction and Historical. Blood vessel tumors of one or another type are not infrequently encountered in the hand, although they are not among the more common tumors. Classification offers somewhat of a problem due to various opinions expressed by authors in this field From a practical standpoint, all vascular tumors are placed in one group—angiomas—and this is subdivided into true angiomas, those tumors showing proliferation of the endothelial element, either as benign angioendotheliomas or malignant angiosarcomas,

Fig. 745 Vessel type angioma in the subcutaneous tissues overlying the proximal joint of the little finger (Wakeman U S Army photo)

and false angiomas, including all those which do not show proliferation of the endothelium aside from the formation of new blood vessels or which show only variations in otherwise preexisting vessels In this latter group are included the majority of the so-called angiomata.

Etiology It is probable that all angiomas arise on a congenital basis, the development and manifestation occurring early or later in life, as the case may be Certainly in studying the embryology of blood vessel formation, from capillary network to enlarged tubes and finally to the stem system with disappearance of certain other coexisting units ample opportunity for anomalous development is apparent and

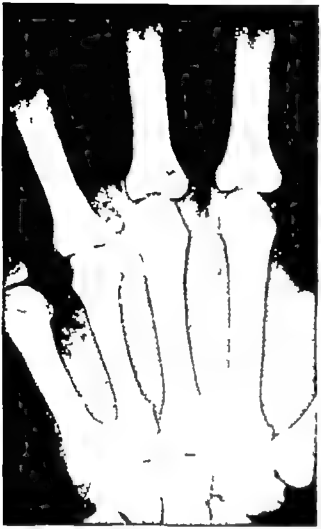


FIG 746 Angioma growing from interosseus muscle. Tumor distinctive by presence of phleboliths.

one often wonders that more of this does not occur

Pathology The outstanding pathologic feature of all angiomas is their vascularity and certain infiltrating powers. The true angioma shows endothelial proliferation to form a mass of cells in addition to the vessels. In the malignant form of angiosarcoma, there is a tendency for the endothelial cell to revert back to its mesenchymal type producing a varied histologic picture, which may simulate carcinoma or sarcoma but in so doing it always retains an angioblastic tendency resulting in formation of new blood vessels The other forms are variously classified by their morphologic picture into capillary or vessel type, or simply elongation and dilatation of preexisting vessels. The phenomenon of metastasis has been attributed to the benign forms of angioma, but while not definitely proved one way or the other, most of these cases probably represent multiple lesions.

Incidence. Out of 570 cases of angioma reported by Geschickter and Keasbey, 40 occurred in the forearm, hand, and fingers.

Location. In the hand, angiomata can be present in practically any tissue from the skin, subcutaneous, nerve, and muscle element, to involvement of bone and invasion of tendon sheaths. The thenar or hypothenar eminences are favored locations, as are the deep spaces in the palms.

Symptoms. There is seldom pain, unless the lesion is so located as to give pressure on nerves or bone expansion is taking place. The patient generally complains of a small compressible tumor which seldom interferes mechanically with the function of the hand If the tumor involves the skin, the cosmetic appearance often brings the patient to the doctor

Diagnosis. Diagnosis is not difficult, as a rule. The tumor is compressible, and enlarges when the venous return is obstructed. On clinical examination it is generally without definite limits.

Treatment. The capillary type needs little attention, as a rule responding well to coagulation, excision, radiation, or application of carbon-dioxide snow The vessel types, on the other hand, require for their cure a most careful and complete surgical dissection which is often very difficult due to the ramifications of the tumor with involvement in and about important structures. The necessity of working under a tourniquet is obvious, but this in a way is disadvantageous, as part of the lesion can readily be missed Large lesions may require surgical removal in stages. In such cases the control of hemorrhage following the release of the tourniquet may be a problem One method found useful is to lower the cuff pressure momentarily, allowing a

small amount of blood to enter the arm Local pressure about the wound causes this blood to extrude from the open vessels, thereby identifying them for ligation or coagulation. This process may be repeated several times, thus controlling most of the opened vessels before final removal of the tourniquet Close postoperative attention of the wound is necessary, as the tissues in these cases often heal poorly The use of sclerosing solutions as injections into the vessel type of angioma has been advocated and in selected cases may be of some value At times it is employed in obliterating small isolated portions of the angioma remaining after surgical removal.

Prognosis. Prognosis is guarded, as recurrences are prone to appear The malignant form (angiosarcoma) may be rapid spreading and fatal.

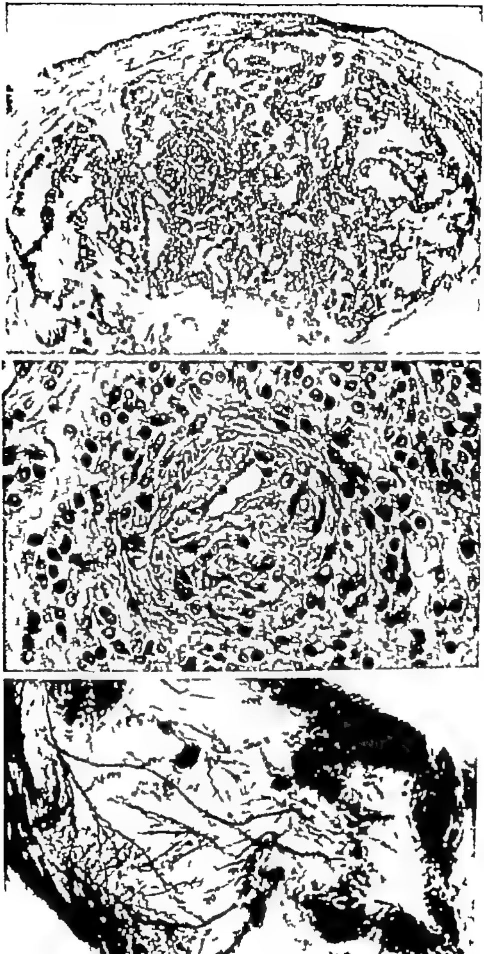
Fig. 747 (*Top*) Congenital lymphedema affecting the right arm of a girl, aged nine.
(*Bottom*) Microscopic appearance of tissue removed in (A) a remarkably large amount of the section is composed of lymph spaces which are surrounded by connective tissue. (× 16) Courtesy Mason, P B., and E. V Allen Amer Jour Dis Child., 50 945 1935)

Lymphangiectasis

Lymphangiectasis is an unusual condition of congenital origin, and when a familial tendency is shown it is known as Milroy's disease. It is doubtful if confusion between this condition and a tumor would occur However, it is mentioned for the sake of completeness because there is some similarity to the angiomas. When the upper extremity is involved, it is generally the entire member, and the condition was present at birth The edema is due to replacement of the normal subcutaneous fat by dilated lymphatics and later fibrous connective tissue, as is readily demonstrated on microscopic section Treatment is difficult, and depends upon excision of as much of the abnormal tissue as possible, utilizing salvaged skin and skin graft to cover the resulting defect.

GLOMUS TUMORS

Introduction and Historical This interesting tumor was recognized as a clinical entity long before it was given its present name by Mason in 1924, who identified the tumor by its structure as arising from the normal neuromyo-arterial glomus. The first recorded cases are credited to William Wood in 1812 under the name of painful subcutaneous tubercle. Barré, in 1920, outlined the clinical aspects of the tumor and emphasized the importance of surgical excision to effect a cure. Although infrequently seen, the tumor has been of interest to the profession as evidenced by the 197 cases reported in the literature up to 1942 by Ottley Some confusion in terminology has been apparent in the past, as cases of glomus tumor have been recorded under various names such as angioneuroma, glomangioma, Popoff tumor, tumeur glomique, angiomyoneuroma, angiosarcoma, etc.



Etiology The normal structure from which the glomus tumor arises is of greater scientific than clinical interest. This neuromyo-arterial glomus lies in the stratum reticulare of the skin and serves as a controlled arteriovenous anastomosis or shunt between the terminal vessels, probably for thermal regulation by the vasomotor system. Such anastomoses were first described by Sucquet in 1860, who demonstrated direct connections between terminal arteries and veins by the injection method and noted their frequency in the palms, soles, fingers, and toes. Hoyer, in 1877, described similar arteriovenous anastomoses in animals. In 1902, Grosser described in detail these structures in man and warm-blooded animals, but found them to be absent in the poikilotherms. The latest and most detailed study of the neuromyo-arterial glomus has been made by Popoff, in 1934, using human material studied by serial section. He describes the structure as consisting of an efferent arteriole from which branches the tortuous anastomotic vessel (Sucquet Hoyer canal), which in turn opens directly into a primary collecting vein. The characteristic feature of this arteriovenous anastomosis lies in the structure of the anastomotic vessel which is endothelial lined and surrounded by longitudinal and circular smooth muscle cells among which appear the "glomal cells" which are epithelioid in appearance with oval or globular nuclei The glomal cells have been described as embryonic muscle cells, angioblasts, and elastoblasts, although their true nature and function are not known. All parts of the glomus are bound together by a delicate collagenous reticulum in which nonmyelinated nerve fibrils are plentiful, and the whole is surrounded by a fibrous tissue capsule. The size of this structure never exceeds 1 mm in diameter The physiology of the normal glomus has been studied by Lewis and Pickering, and Grant and Bland in 1931, and it is their belief that these anastomoses serve to regulate peripheral blood flow and, therefore, the peripheral blood pressure and temperature There is no known cause for a normal glomus to develop into a glomic tumor, although in the literature trauma has been cited as the activating agent in some cases.

Pathology The glomus tumor represents a hypertrophy of the normal glomus The gross appearance is that of a small encapsulated tumor, never over 1 cm. in diameter, and in its subungual location being from 2 to 6 mm. in diameter It is generally of deep red or purple color and on cut section it exudes blood, following which it becomes gray in color The microscopic appearance of the tumor, by reason of its origin, resembles closely that of the normal glomus, the principal difference being a marked increase in number of glomal cells and nonmyelinated nerves. Similarity of the microscopic picture to that of the glomus coccygeum is notable.

Incidence This small tumor, which has a clinical picture characterized by pain, is found a little more frequently in males than in females The incidence among Jewish people is increased, due probably to their recognized *affinity* to sympathetic nerve disturbances. There is no special age group for the occurrence of this tumor,

FIG. 748 (*Top*) Glomus tumor Low-power photomicrograph of the encapsulated subungual tumor covered by the elevated nail bed.

(*Center*) One of the tumor vessels cut somewhat tangentially with a small, empty endothelial-lined lumen surrounded by a somewhat irregularly arranged muscular coat, outside of which are the "epitheloid" cells with their clearly defined cell membranes. Each cell is separated from its neighbor by a delicate collagen fiber

(*Bottom*) Photomicrograph of a frozen section stained by a modified Gros technic, showing the large number of nerve fibers passing from the capsule along the stroma between the tumor vessels with their epitheloid cells (Courtesy Stout, A. P Amer Jour Cancer 24.261 264 267 No. 2 June, 1935)

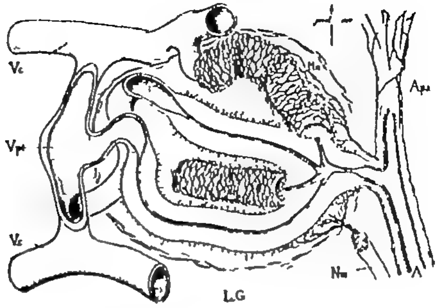


FIG. 749 (*Top*) Schematic reconstruction of a glomus. (A) Superficial preterminal artery (Apa) Terminal branch entering capillaries. (L) The side branch is the afferent artery entering the glomus, dividing into four neuromuscular arterioles. The elastica of the afferent arteriole disappears as soon as the arteriole enters the glomus. The wall of the vessel becomes thick due to an increase in smooth muscle fibers which terminate abruptly with the beginning of the venous segment. The efferent glomic vein leads into a collecting vein (V pe.) which is dilated and thickened at the junction and in turn leads into the superficial veins (V.c.) Mn is the rich perivascular network of nerves, showing connections with the peri arterial sympathetic nerves as well as myelinated sensory nerves to the skin (After Masson.) (Courtesy Pack, G L. Tumors of the Hands and Feet, St. Louis, The C. V Mosby Co., 1939)
(*Bottom*) Diagram of glomus tumor

cases in the literature being reported in individuals between six and 70 years old with the majority of the cases falling in the 20- to 40-year-old period.

Location. The glomus tumor is subungual in location in about one-half of the cases and at this site shows a greater frequency in women than in men. The tumor, however, *may appear on any part of the* surface of the body It has been reported on both upper and lower extremities, on the trunk, and even on the eyelids. The upper extremity is predominantly involved. Several cases of multiple tumors have been reported Plewes. In one instance six occurring on one foot, and in another instance four occurring on one finger

Symptoms. The constant and outstanding symptom of the glomus tumor is pain, and it is generally severe. It may be con*stant or intermittent* and may arise spontaneously or by contact, or by change in temperature. The pain is described as stabbing or burning in character and often

radiates up the extremity to the trunk.

Diagnosis. The diagnosis is, as a rule, not difficult if the condition is in the mind of the examiner. The clinical appearance of the tumor in the subungual location is quite characteristic. It is usually seen as a bluish or cyanotic *discoloration 3 to 5* mm. in diameter under the fingernail. The lunula of the nail is often blurred and the nail itself may be raised centrally with increase in the convexity of the transverse plane. There may be associated vasomotor disturbance with vasodilatation of the affected member. In cases suffering from exquisite pain and tenderness, a protective posture habit of the affected part may be assumed. In some cases, erosion of the distal phalanx may occur which can then be detected roentgenographically. When the lesion occurs elsewhere, it is usually found in or just under the skin as a small painful nodule. The differential diagnosis in the subungual location includes subungual melanoma, exostosis, clavus papilloma, fibroma, and hemorrhage. In other locations it must be differentiated from many small tumors, but particularly neuroma, neurofibroma, and fibroma.

Treatment. Treatment of *this tumor* consists of complete surgical removal, and no other method—including roentgenotherapy—is of benefit. There are no reported cases of recurrence following adequate surgery.

Prognosis. The prognosis for cure is good.

SUBUNGUAL MELANOMA

Introduction and Historical. Subungual melanoma, or "melanotic whitlow," is a highly malignant melanoma requiring urgent treatment. *This type of melanotic* tumor was first described in the literature by Jonathan Hutchinson in 1886, who described it as a melanotic whitlow due to coexisting inflammation and apparent limitation of the lesion to the distal segment of the affected digit. He described the "narrow band of black bordering the inflamed part," and called it a pathognomonic sign of the disease.

FIG. 750. Subungual melanoma. Note the pathognomonic border or halo of black pigment at the edge of the involved nail. (Courtesy Pack, G. T. Tumors of the Hands and Feet, St. Louis, The C. V. Mosby Co., 1939.)

Since this time, considerable literature has accumulated on the subject, and the lesion has been given various names such as onychial melanoma, melanosarcoma, melanocarcinoma, and melanoblastoma.

Etiology. Trauma has here again been given a prominent rôle as an etiologic factor, a history of such being obtained in 50 per cent of cases. In most instances there is no history of a mole prior to development of the tumor, although in some reported cases a pigment spot has been present under the nail for years. The genesis of the tumor is attributed to cells associated with the tactile end organs of the nail *bed, and for this reason many authors in*clude it in the group of neurogenous tumors. In the present discussion, however, it will be considered as an entity and its differential diagnosis taken up with this in view.

Pathology. The gross appearance of the tumor is that of a pigmented, fungating

mass often ulcerated, involving the sulcus of the nail and the nail matrix. There is frequently a coal black border at the junction of the tumor with the normal tissue.

Microscopically, evidence of moderate inflammatory reaction may be present in addition to the tumor tissue. The latter is composed of two types of cells one, a fusiform spindle-like cell with infrequent mitosis, hyperchromatic nuclei and both intra and extracellular pigment, the other a spherical or polygonal cell in sheets or *pseudo-alveolar arrangement, with more* mitoses and less pigment.

Thus, the first type of cell resembles sarcoma and the latter carcinoma, and although this has aroused much discussion and difference of opinion as to the actual origin of the melanin-producing cell, it is primarily of academic interest, as the tumor runs much the same clinical course regardless of its histologic appearance. There is marked variation in the amount of pigment present, lesions ranging from no pigment to a coal-black appearance. Metastases may be similarly pigmented or nonpigmented, and occur through the lymphatic and blood streams.

Incidence The subungual melanomata occur in white individuals (rarely in Negroes) during the latter part of adult life Average age is 58 7 years according to Pack. The sex incidence is about equal When all melanomas are considered, the incidence of the subungual type is not high being variously reported from 1 to 3 per cent for both hand and foot.

Location. The tumor on the upper extremity is practically always found on the thumb and makes its appearance under the nail or protruding from the sulcus at the edge of the nail. When the tumor is present on the foot, the great toe is the favored location.

Symptoms. *Although this tumor is almost always associated with infection, and* occurs in an ordinarily tender area of the body, pain is reported never to be a conspicuous symptom—even in the late stages of the local disease. The patient complains principally of the presence of the lesion and of the discharge in the event ulceration has occurred.

Diagnosis. In the early stages a black spot only may be noted under the finger nail. With growth of the tumor, the nail splits or is decompressed surgically and a fungus-like growth makes its appearance. A common site for the tumor is in the sulcus along the margin of the nail. Here it *presents a granulating surface usually with* a pigmented border Sooner or later the tumor ulcerates, and weeps a thin brown fluid which stains clothing The entire nail is lost as the lesion progresses, and some degree of infection is also common. Differential diagnosis must be made from the infections that occur about the nail which are usually acute in onset, and also from other subungual lesions such as subungual hematoma, fibroma, glomus tumor, and carcinoma of the nail bed Benign tumors do not break through the nail, and therefore this point becomes of diagnostic significance The fungating lesion may not be pigmented However, the narrow pigment border is usually present

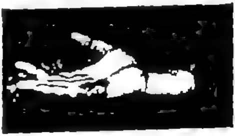


FIG. 751 Melanosarcoma of hand.

Treatment. For such a malignant lesion as the subungual melanoma, early and adequate surgery offers the only hope of cure, and most authors advise amputation well proximal to the tumor, and at a later date *(approximately two weeks)* extirpation of the regional lymph nodes. Roentgen therapy has been used, but in most instances the response is slight. If extremely heavy

doses are given a useless, painful finger results.

Prognosis The prognosis in general is poor, although the subungual melanoma offers the best chance of all the malignant melanomas for cure, due to slow growth, late dissemination, and location.

Local recurrences are common, and metastases occur along the lymphatics and in the regional glands. Generalized dissemination of the tumor follows with its resulting effects The absence of metastases at the time of treatment of the initial lesion is favorable but does not insure a cure. Figures given by Pack for five-year survival with no evidence of recurrence are 18 75 per cent for all subungual melanomas

Malignant melanomas may appear elsewhere on the hand other than subungual Bickel, Meyerding and Broders in reporting 107 cases of malignant melanoma of the extremities noted seven cases subungual (finger) in location, three cases arising elsewhere on the fingers, and two cases arising from other locations on the hand

The pathology, course and treatment is essentially that outlined for the subungual variety

CARCINOMA OF NAIL

Introduction and Historical This neoplasm, which is generally not considered with carcinoma of the hand, deserves mention even though it is of extremely infrequent occurrence. Up to 1939, some 19 cases were reported in the literature, 13 of which were on the hand. The lesion is distinguished from the malignant melanoma described elsewhere.

Etiology Most cases give a history of trauma or infection which is resistant to treatment. Silverman reports a case following a chronic paronychia of over one year's duration on the thumb Pardo-Castellō records the origin of the condition in association with Bowen s disease.

Pathology This squamous-cell epithelioma arises from the nail bed or groove and is of prickle-cell type. It is of low-grade malignancy as a rule, involves the structures locally, and may even invade or erode the bone

Incidence No other information obtained

Location. The commonest site is on the thumb, and the next commonest on the index finger The right side is more frequently involved than the left.

Symptoms. Pain is usually a symptom as the lesion is expanding in a tender area. This seems in contrast to that stated for melanotic whitlow

Diagnosis. The diagnosis is made by the appearance of a warty like growth in the sulcus of the nail. It resembles a chronic paronychia which is resistant to treatment

Treatment. The treatment of this condition is either amputation or radiation therapy Mason advises amputation and dissection of the glands in the axilla.

Prognosis. The prognosis for cure is good. There is seldom a recurrence unless metastasis has already occurred

CARCINOMA OF HAND

Introduction and Historical The first reference to carcinoma of the hand was made by Behrends in 1827 Since this time, considerable literature has evolved on the subject because carcinoma is one of the most important and frequent of malignancies at this site. Shortly after the advent of roentgenotherapy, reported cases of roentgen dermatitis of the hand with subsequent carcinoma began to appear, and the profession is only too well aware of the sacrifices made by many of its members as a result.

Etiology In no other malignant lesion does the rôle of chronic tissue irritation play such a prominent part or is so well recognized as an etiologic factor This does

not mean a single traumatism. While only 10 per cent of cutaneous carcinomas occur on the hands, Mason states that 40 per cent of these arise as a late result of injury, infection, or scar The particular susceptibility of radiation and thermal scars to undergo malignant changes is well known, and Ullman states that this type of scar is responsible for 80 per cent of the carcinomas developing in scars The type of trauma or tissue damage is of an irritative nature as a rule, and its action is generally over a period of time. The more common irritative agents are the roentgen, sunlight, contact burns, and chronic infections with resulting scars and ulcerations. Chemical irritants such as acids, alkalies, tars, pitch oils, paint, etc., likewise are offenders, and mechanical irritation over a prolonged period may also be cited as a cause.

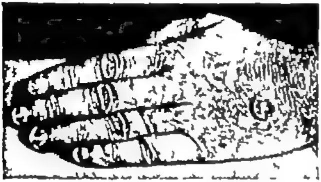


FIG. 752 Typical appearance of an early squamous-cell epithelioma of the *dorsum of the hand present three months.* (Courtesy DeBell and Stevenson Surgery Gynecology and Obstetrics 63 224 1936)

Pathology The gross appearance varies from small fissures or cracks which are unhealed to areas of hyperkeratosis or actual tumor formation with or without ulceration. The microscopic picture is that of an epithelioma, of either the squamous or basal-cell types, and most of them are of low grade malignancy The melanotic type of malignancy may also occur, but this has been described elsewhere. Lesions developing on the backs of the hands are almost entirely of the squamous-cell type.

Incidence Carcinoma of the hand occurs slightly more often in the male than

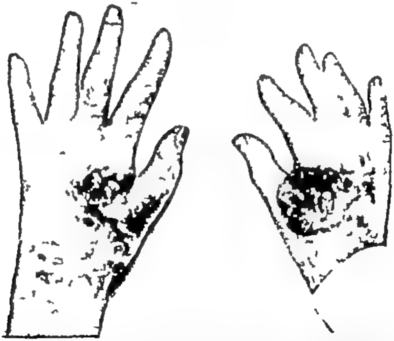


FIG. 753 Showing squamous epithelioma of both hands. The patient for 40 years had painted Pullman cars using both hands and placing the paint brush between the thumb and forefinger at which site the epithelioma originated growing upward over the dorsum of the hands. The right hand was amputated. The left hand was treated with radium rays. There is no evidence of any disease four years later (Courtesy Adair F E Surg. Clin. N Amer., 13 425 No 2 1933)

in the female, various services reporting a ratio of from 2 5 to 1 to 4 to 1, and individuals presenting this lesion are mostly over 30 years of age. While the incidence of carcinoma is high among the malignant tumors of the hand, it is low when all tumors of the extremity are considered.

Location. Since the only structure of the hand which can give rise to carcinoma is the skin, the lesions necessarily appear on the surface, and by far the greater majority of them occurs on the back of the hand. In a series of 61 cases on the upper extremity reported by De Bell and Stevenson 84 per cent occurred at this site. The right hand is involved a little more frequently than the left, with the exception of carcinoma following roentgen dermatitis.

FIG. 754 Early skin changes on volar surface of tip of index finger secondary to radiation. Note hyperkeratosis and marginal telangectasia. (Wakeman U S Army photo)

Symptoms. Since the lesions appear on the skin, they are always visible and in most instances some pain is complained of Ulcerations may be present, and these are often secondarily infected.

Diagnosis. The possibility of carcinoma in any lesion of the skin on the dorsum of the hand in an individual over 30 years of age should be strongly suspected because these lesions are, as a rule, slow to progress and watchful waiting is indulged in far too frequently Pain developing in a long standing scar or sinus on the back of the hand is probably indicative of malignant change. Later in the course of the disease the tumor generally manifests itself as a hard nodular structure which is very apt to ulcerate and become fungating. Metastasis to the regional lymphatics appears relatively late in the course of the disease, sometimes a matter of a year or two after the condition has been diagnosed

Treatment. The treatment for carcinoma of the hands can be divided into two phases first, and most important, is prophylactic treatment of areas in which carcinoma is likely to develop and thus consists of eradication of all types of chronic irritation or infection, and if changes have already occurred in the skin which are likely to persist and result in malignant degeneration—such as scars from roentgen dermatitis—the involved skin should be removed surgically and replaced by normal healthy skin by means of either a pedicle or a split-skin graft, as the need might be. Second, by the treatment of the cancer after it has developed, and this means eradication of the local lesions by wide resection to include any other areas of skin which might later break down. In addition Handley and other authors advised early and complete removal of the axillary and epitrochlear glands for both treatment and prophylaxis It seems advisable to do more than necessary rather than to risk the fatal termination of the disease. Good reports on the treatment of the lesion by irradiation can be found. In a large, recently published series by Braddon unusually good results have been recorded. The author stresses accurate dosage, distribution and time of treatment.

Prognosis. The prognosis naturally depends upon the extent of the lesion at the time it is first seen. The local lesion in an early stage and without metastasis offers an opportunity for cure. Once metastasis is present the outlook is gloomy

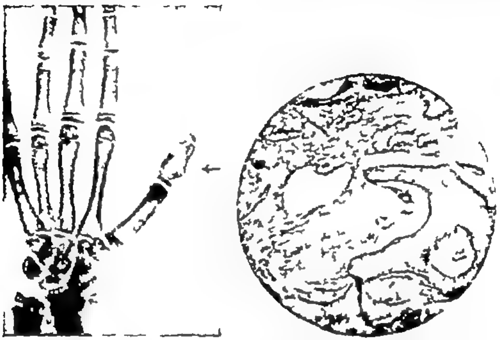


FIG. 755 (*Left*) Cyst of the proximal phalanx of the thumb (osteitis fibrosa) Shows multicystic expansion of phalanx. No sign of fracture. (*Right*) Cyst contents. Bone trabeculae undergoing erosion in the midst of delicate connective tissue. An early phase of osteitis fibrosa. (Courtesy Platt H. Brit. Jour Surg., 18 21 No 69 1930)

BONE TUMORS

Almost all tumors of bone which appear elsewhere in the skeleton may be present in the hand Due to the small size of the hand bones these tumors appear in miniature, yet in most instances retain the characteristics that they have elsewhere. Malignant bone tumors are extremely uncommon distal to the forearm. The benign tumors are fairly well represented with but few exceptions Bone cysts are included with the tumors due to their similar radiologic appearance and diagnostic problems

CYSTS OF BONE

Introduction and Historical. Here, as in the case of tumors, cysts of the hand bones represent on a miniature scale cysts which occur in other parts of the skeletal system

Etiology The cause of the cysts is unknown, but many theories have been advanced, such as traumatic hematoma, inflammation, faulty calcium metabolism and progressive osteoclastasia. The simple or solitary bone cysts are of the osteitis fibrosa cystica type Some authors believe there is close relationship between the bone cyst and the giant-cell tumor or xanthoma of bone, based on the finding of apparent transition stages between these two conditions. They point out that the cysts tend to occur in young individuals, the variants in the adolescent stage, and the giant-cell tumors after fusion of the epiphyses.

Pathology Platt divided bone cysts of the hand into two types. The simple or solitary cyst he classifies as osteitis fibrosa cystica. This cyst is incompletely filled with tissue, has a tough, fibrous lining, and may on microscopic section show some xanthomatous tissue. The other type of cyst is the chondromatous or myxochondroma

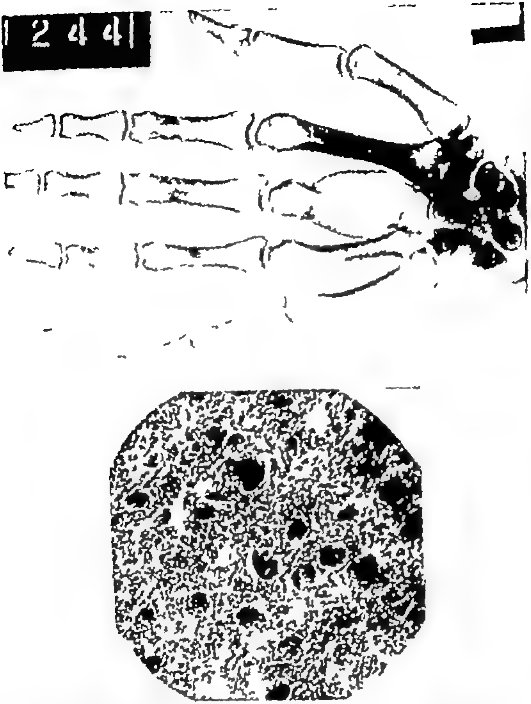


Fig. 756 (*Upper*) Central metacarpal giant-cell sarcoma. Roentgenogram, anteroposterior showing involvement of third metacarpal bone the expanded and thinned-out cortex, the trabeculations, and the limitation to one bone.
(*Lower*) Section of tumor in (A) showing giant cells and stroma. (Courtesy Dunkes Emile Annals of Surgery 85 912 No 6 1927)

tous. In these there is a cavity filled with sago-like material mixed with a friable granulation like tissue. There is no fibrous tissue lining, and some cartilage may be present. This type of cyst, he admits, may belong with the enchondromas.

Incidence. The sex incidence is about equal, with slight predominance in the male As far as age is concerned, most of these occur under 25 years but may occur at any age. Silva in 1912, in a tabulation of 97 bone cysts, found seven of this number to be in the phalanges and one in the meta carpal of the hand The osteitis fibrosa cyst is quite rare, but when all cysts are in cluded, Clapp found that out of 34 cases

Fig. 757 (*Left*) Clinical and (*Right*) x ray appearance of a benign giant cell tumor of the fifth metacarpal Note "soap bubble" appearance of the bone trabeculae Excellent result obtained by amputation of little finger with its ray thus narrowing the hand (Courtesy of Dr Donald Wells, Hartford, Conn.)

13 were in the miniature long bones, and Geschickter and Copeland, out of 175 cases of the osteitis fibrosa type, found that 16 were of the smaller bones

Location. Bone cysts are found more frequently in the phalanges than in the metacarpals, and the majority are in the proximal phalanges Most of these are located in the little finger, and the next in frequency is the index finger

Symptoms. Like bone cysts in other locations, their presence is most apt to be detected by fracture, often a result of a minor injury It can be assumed that symptomless growth of the cyst has been going on for a long time before the bone becomes so weakened as to break. Other symptoms consist of local swelling of the bone and occasionally some mild pain

Diagnosis. The diagnosis is made principally by means of the x-ray, where it is seen that the cyst originates in the metaphysis near the growing end. In the hand, this means the distal end of the metacarpal or the proximal end of the phalanx. The cyst extends into the shaft preserving the integrity of the epiphysis. The roentgen appearance of a cyst may remain unchanged for a long time. The area of bone involvement is sharply demarcated, with a smooth, well-defined wall The differential diagnosis includes giant-cell tumors and other neoplasms and infections.

Treatment. In most instances, operative treatment is advised and it is often not until then that the diagnosis is entirely settled. In general, the treatment is that of curetting out the material in the cyst and the cyst lining, sterilizing the resulting cavity with pure carbolic, and obliterating the space by filling it in with bone chips. Indications for operations are active growth

Fig. 760 Multiple intraosteal chondromata in girl eight years old Involving the whole skeleton Heavy radiation local improvement (Courtesy Kolodny A. Surgery Gynecology and Obstetrics 44 94 1927)

Fig. 758 (*Top*) Roentgenographic appearance of a benign [illegible] of the forefinger The chondroma is a central bone-destructive [illegible] cartilage separated by strands of connective tissue.

(*Bottom*) Microscopic appearance of benign chondroma [illegible] Geschickter C. F Radiology 16 158–159 No 2 Feb., 1931.)

of the cyst or the presence of a very thin shell with impending danger of fracture. Cysts of the bone which are discovered roentgenographically by accident and which have a very thick wall are probably quiescent and treatment can be delayed.

Prognosis. The prognosis for cure is good.

Exostoses

True exostoses of the bones of the hands are very rare, and when they are seen they are generally about a joint, having developed secondary to injury of that part with setting up of a traumatic arthritis. On occasion, a subungual exostosis of the terminal phalanx may occur. These generally appear on the index finger. Because of their location, they have been mistaken for other types of subungual tumors. They may continue to grow until they push up the nail and become quite painful. When they are removed, they are often observed to have a cap of cartilage, suggesting that they are closely related to osteochondromas. Treatment of the condition is simple excision of the exostosis, being certain to get all of the cartilage as well.

Xanthoma

These are benign tumors seen occasionally in the bones of the hands. They begin in the epiphyses but may spread rapidly to involve the whole bone, as a rule showing the characteristic soap-bubble appearance. The histologic picture is consistent with xanthomas elsewhere, and the diagnosis can be frequently established before surgery. The metacarpals are more commonly involved. The symptoms as a rule are not pronounced unless pathologic fracture occurs, and this latter may be the first indication of trouble. If the tumor is large, a diffuse increase in size of the bone may be detected externally. Treatment depends upon the extent of the lesion, the lesser ones being arrested or even cured by x-ray therapy. The larger ones which have destroyed much of the bone generally require surgical intervention. Where resections of the bone are done it is possible in most instances to make replacements by means of bone graft.

Chondroma or Enchondroma

Introduction and Historical. These are congenital tumors, almost entirely restricted to the hand, where they occur singly or multiple in the phalanges and present a more or less characteristic picture.

Fig. 759. Cyst of phalanx of thumb which proved to be a chondroma.

Etiology. The congenital origin of these tumors is believed to be due to cartilage rests where they represent potential joint cartilages in the phalanges. This possibility may explain their frequent occurrence in the hands, where multiple joints are present.

Pathology. The gross microscopic picture is that of cartilage, which at times may show some calcification within its substance and at times break out of the confines of the bone and extend into the soft tissues. Some periosteochondromas have been described but they are exceedingly rare.

Incidence. These tumors are generally recognized in individuals under 30 years of age and this is another factor indicating their congenital origin. Statistics on sex or race incidence were not obtained.

FIG. 760 Multiple intraosteal chondromata in girl eight years old involving the whole skeleton. Heavy radiation gave only local improvement. (Courtesy Kolodny A. Surgery Gynecology and Obstetrics 44 94 1927)

Location. The phalanges are the site of choice—particularly the proximal phalanges—though when the tumors appear in numbers they may be in many of the phalanges and the metacarpals as well.

Symptoms. The symptoms are mild, if any are present at all. There is a uniform hard expansion of the phalanx causing no disability. Pathologic fracture, which occurs in about 10 per cent of cases, may be in size, and treatment of these can be deferred.

Prognosis. The prognosis for cure is good.

Osteochondroma

Osteochondromas may rarely occur near the head of the metacarpals and are often called "ecchondromas" in contrast to the enchondromas previously described. They are usually visible roentgenographically and


A B C

Fig. 761 Case N T
(A) Osteochondroma of radius. Has had three previous operations.
(B) Tumor with end of radius was excised a spike of radius thrust into the carpus, and a bone graft was added. Ulna was excised well back.
(C) Recurrence of tumor in radius and ulna, necessitating amputation.
Conclusion Best opportunity for cure is at first operation.

the first symptom, and the tumor is discovered by x ray

Diagnosis This is based on the roentgen finding of a centrally located rarefaction of the bone of the phalanx. If the tumor is large, the bone is expanded, but a thin osseous covering is generally preserved. When multiple areas of such an appearance are present, the diagnosis is ... certain. In differential diagnosis x... bone cysts are the principal con...

Treatment. The treatm... tumors, when indicated, is ... taken to remove all the ... rial to avoid recurrence ... excision may have bone chips result ... It is rare to to ... cure. Small go ...

if of any size may give local pressure symptoms. The treatment consists of surgical removal, taking a broad base along with the growth, as they are prone to recur

Osteoid Osteoma

This ben... tumor may occur in the ... adult individual but it is rare ... When present, the lesion ... clinically by localized ... X ray examination usually ... circumscribed, osteolytic ... cancellous or ... bone cal... is ... bone

Fig. 762 An osteoblastic osteoid tissue forming tumor of a metacarpal bone. (Courtesy Joffe, H. L. and L. Mayer Arch. Surg., 24 500 Apr., 1932)

include both tumor and infection, the latter being suggested by the pain and local tenderness although other signs of infection are absent.

Surgical removal of the lesion is said to result in prompt and complete cure.

Malignant Tumors

Osteogenic Sarcoma. These tumors are very rare, although they do occur occasionally in the metacarpals of the hand. A history of trauma is obtained in approximately half the cases. Pain is an early and persistent symptom of this tumor which makes its appearance generally in the second and third decades of life. Early roentgen studies combined with biopsy should determine the diagnosis and facilitate early and radical amputation Coley and Higinbotham state that they believe many of

Fig 763 Osteoid osteoma of carpal navicular Note osteolytic area about central zone of condensation. (Courtesy of Dr Bradley L. Coley New York. U S Army Photo)

Fig. 764 Low-grade osteogenic sarcoma of proximal phalanx of fifth finger Male, aged 30 years. Two operations elsewhere for inflammatory disease. Amputation of fourth and fifth fingers through metacarpals. Alive and well almost ten years later (Courtesy Pack, G T Tumors of the Hands and Feet, St. Louis, Mosby 1939)

these tumors are secondary to benign chondromas and that osteogenic sarcoma in the hand offers a better prognosis than when it occurs elsewhere in the body, as evidenced by their survival figures. When the clinical course of the tumor is not arrested, its metastatic manifestations are the same as when the tumor originates elsewhere.

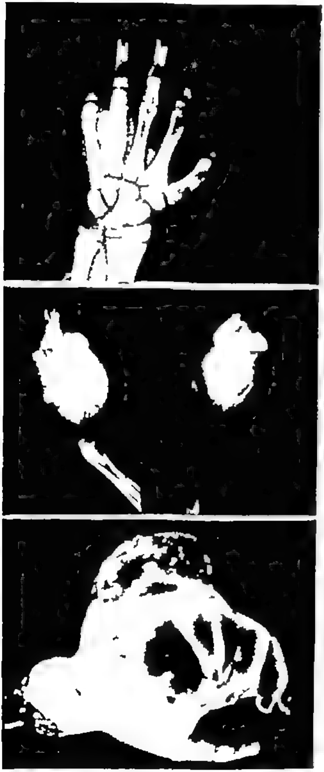


Fig 765 Ewing's tumor of the metacarpal.
(*Top*) Early stage. Proliferation of periosteal layer of bone.
(*Center* and *Bottom*) Advanced stages. (Courtesy Dr F M. McKeever Los Angeles.)

Chondrosarcoma. This form of malignant bone tumor should be mentioned for completeness although specific occurrence in the hand was not noted in the literature. In general it occurs in older individuals and follows a more chronic course It is believed to arise from mature cartilage such as is present in a cartilage rest in bone, or capping an osteochrondroma. When it is recognized, treatment by radical amputation is indicated

Ewing's Tumor This tumor also may occur in the hand but more cases are reported in the bones of the feet. The clinical features are, here again, characterized by pain, and frequently operation is performed for infection due to the low-grade fever which is usually present. Coley and Higinbotham state that the characteristic features of fusiform enlargement and periosteal splitting are less often demonstrated in small bone involvement, and recommend aspiration biopsy for diagnosis. They further believe that the treatment of choice is heavy irradiation followed by amputation and a postoperative course of Coley's toxin

Metastatic Tumors

Metastatic tumors of bones of the hand are extremely rare and very few cases are recorded in the literature. It is probable that they may occur more frequently than they are detected, since the patients are often in an extremely debilitated state with generalized bone metastasis from the malignancy Mention is made that in two of the cases recorded the source of the primary tumor was in one instance the parotid gland and the other the breast (carcinoma)

SARCOMA

Introduction and Historical The term sarcoma implies a malignant tumor arising

from cells of mesothelial origin. Under this definition all malignant tumors of the hand are sarcoma with the exception of those arising from the skin and its glands and the fibrillary neuromas.

From a practical standpoint, sarcomas arising from specific structures, such as bone, nerve sheath, tendon sheath, muscle, et cetera have been considered with the tumors of these structures, and similarly the melanotic malignancies are considered following discussion of subungual melanoma

This arrangement leaves the fibrosarcoma to be considered separately, although some authors would insist that many of the abovementioned sarcomas really belong in the latter group, but the practical features outweigh the technicalities of classification Once a sarcoma of any type is diagnosed the subsequent clinical course follows a more or less common pattern

Etiology Fibrosarcoma is considered to arise spontaneously from connective tissue elements or from benign tumors of fibrous tissue origin Trauma as an etiological factor is frequently reported, and some cases present convincing evidence, however, most authors agree that there is little if any relationship Carrol and Martin in reporting their series of cases, found only 5 per cent gave a definite associated history of trauma.

Pathology The microscopic picture of fibrosarcoma is so varied there is little wonder that differences of opinion as to origin, type, classification, and malignancy exist From the clinicians' standpoint, the acceptance of the views of one pathologist would seem more practical than to become entangled in such a controversial subject The common denominator is the fibroblast and extra cellular material it produces The cells vary in shape, maturity, arrangement, and frequency of mitosis, and the extra cellular material may be scanty or large in amount giant cell may or may not be present. Associated conditions of necrosis, hemorrhage, calcification, or mucoid degeneration may be evident. Other tissue elements such as muscle fibers or fat may be present as the tumor is invasive in nature and this often leads to confusion as to origin when a single biopsy specimen is examined

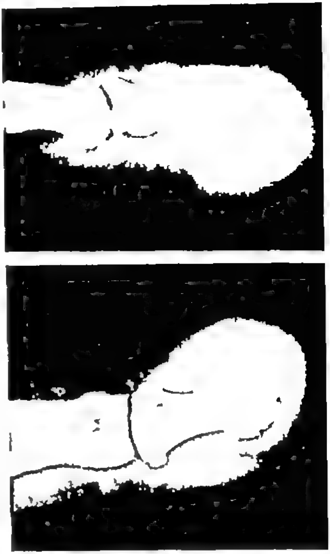


Fig. 766 Case J A. Fibrosarcoma. Starting in subcutaneous tissue five months previously it grew to a firm, solid tumor After amputation of this index finger and distal two-thirds of its metacarpal the tumor did not recur

Incidence Fibrosarcoma of the extremities in relation to all admissions is reported as 1 2400 by Wilson and 1 4000 by Meyerding, Broders and Hargrove Of these approximately ⅝ arise in the lower extremities and ⅓ in the upper extremities. Although exact statistics could not be obtained, the incidence of this lesion arising in the hand is a very small percentage of the total for the upper extremity Thus Beck, in a report of 42 extremity cases,

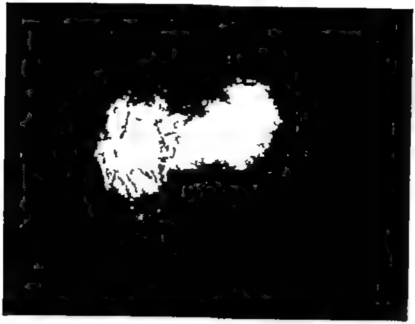


FIG. 767 Fibrosarcoma of hand.

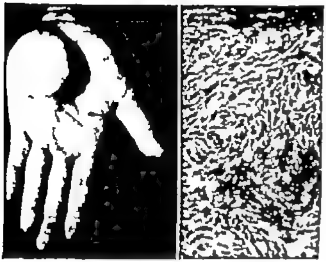


FIG 768 Fibrosarcoma of the hand in 39-year-old white man with a history of gradual enlargement over a period of 30 years. Photomicrograph shows similarity to simple fibroma (Courtesy Wilson, D A. Tumors of the subcutaneous tissue and fascia, Surg Gynec. and Obstet., 80 502 1945)

states 3 involved the hand, and of these 2 were neurogenous in origin. Wilson, reporting on a total of 111 extremity cases, found 7 on the hands and feet.

Incidence as to sex is about equal, with some authors giving slight predominance to the male. The tumor may occur at all ages but the 3rd 4th and 5th decades, with an average age in the late thirties, produce the greatest number of cases.

Location Hardly enough cases have been reported giving the exact site of origin in the hand to be able to draw any conclusions as to predilection of site. Presumably the tumor may arise in any area.

Symptoms The presence of a tumor or the increase in size of a pre-existing tumor is what usually causes the patient to seek medical advice. Pain is seldom complained of, unless the disease is advanced or causing pressure on a peripheral nerve.

Diagnosis. The diagnosis is sometimes difficult and often remains obscure until microscopic section is made. The history of rapid growth of a small pre-existing tumor often of several years' duration is significant. Wilson states that 90 per cent of fibrosarcomas are 5 cm or over in diameter when seen, whereas 85 per cent of fibromas are under 3 cm in diameter This dictum, however, does not necessarily apply to the hand

The tumor may vary greatly in consistency and in fixation. It is more commonly superficial than deep *Excluding* microscopic section, the most conclusive evidence of its malignant nature is the tendency for local recurrence within one year after excision

Such features as anemia, leucocytosis, and

sometimes fever, which are often associated with other types of malignancies, are seldom present early

Metastases may be late, but when they occur they are usually via the blood stream to the lungs, although regional lymphatic spread may also be present.

The differential diagnosis includes all soft tissue tumors, but fibroma, lipoma, xanthoma and synovioma are probably the most important.

Treatment. When positive proof of the nature of the tumor has been obtained, amputation well above the lesion is agreed upon as offering the best chance for cure Local excision can be performed if wide excision does not prove too crippling A recurrence after local excision is definite evidence of the need of amputation X ray therapy is reserved for palliative treatment in advanced cases with metastases and may be used on cases refusing surgery Coley's toxin has been used but is not of proven curative value.

Prognosis. Survival figures for fibrosarcoma of the hand are not available, but judging from the statistics on fibrosarcoma of the extremities, the prognosis is poor Wilson reports a mortality rate of ⅔ in his series. Meyerding, Broders and Hargrove observed that all of their cured cases had a low grade of malignancy and concluded that cure of a given case is perhaps more dependent on the type of tumor than the amount or type of surgery

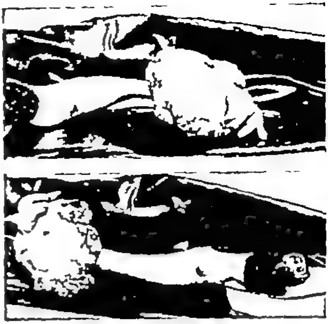


FIG. 769 Case A. B., aged 31 Fibrosarcoma. When 17 years old a toy cannon exploded leaving considerable débris in the hand. Tumor started in thenar cleft and grew to nine inches in diameter in ten months, at which time the arm was amputated. The amputated limb is shown in the illustrations. The patient died from sarcomatosis three months later

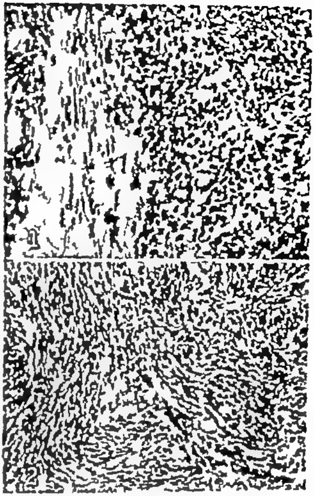
KAPOSI'S SARCOMA

Introduction and Historical. In 1872, Kaposi described this lesion and named it idiopathic multiple pigment sarcoma. Since this time various names according to the author's views of cell origin have appeared, but generally the condition goes under the name of Kaposi's sarcoma. It is given but brief consideration as it is rare, but occasionally the lesions appear as tumors on the hand.

Etiology The disease appears spontaneously, although occasionally trauma is noted prior to the development of some of the lesions.

Pathology Pathology of the disease is characterized by the fact that all stages can be seen in a single lesion The lesion developing in the skin first appears as a macule which is hyperemic but later becomes cyanotic due to stasis of the blood, and finally hemorrhage occurs followed by pigmentation The microscopic appearance of the first stage resembles a cavernous hemangioma. Following this, fusiform cells make their appearance and they proliferate rapidly, sometimes resembling a fibrosarcoma. Some inflammatory reaction and round-cell infiltration is seen This led early writers to question whether the disease was neoplastic or inflammatory The tumor cells are believed to arise from the endothelium and the late picture of the disease is one of invasion of every organ.

A



B

FIG. 770 (A) Kaposi sarcoma in skin. Photomicrograph of a section of skin This is a very early lesion showing the cavernous sinuses lined by endothelium.

(B) Later stages of Kaposi sarcoma.

(1) Photomicrograph of a section taken from a subcutaneous area. This is an older lesion than that shown in (A) Now there is only a suggestion of sinus formation. There is proliferation of the endothelial lining cells, and some of them show spindling

(2) Photomicrograph of a well-developed lesion. There is almost no sinus formation. Practically all of the endothelial cells have undergone spindling so that the tumor resembles neurofibroma or fibrosarcoma (Courtesy Aegerter E. E., and A. R. Peale Arch. Path., 34 415 1942.)

Incidence. Most of the cases occur within a geographic area—from central and southeastern Europe to include Russia, northern Italy, and Poland. It occurs from the fifth to the seventh decades of life and is much more common in males than in females, the incidence being approximately 20 to 1 Laborers and outdoor workers are particularly affected Some authors report a higher incidence in Jewish people

Location. The disease is primarily in the skin and most often begins on the lower extremity Lesions may occur on the hand as well as on any other part of the body

Symptoms. There is an occasional local pruritus The symptoms are principally those associated with the disease in general namely, wasting debility, and eder

Diagnosis is made by observation of the development of a typical nodule. The lesion never regresses, although it may remain stationary for some period of time. It looks like a neoplasm in the way it extends to the adjacent skin and subcutaneous tissues, blocking the lymphatics and producing edema. A biopsy of a lesion will confirm the diagnosis histologically Persons suffering with this disease almost always present anemia with monocytosis

Treatment. Radiation therapy has been the best treatment for this condition Small doses of low voltage are given as necessary Arsenicals are also said to be of some help.

Prognosis. ... lasts from ... months to ... It usually runs over a ... to ten years

and is always fatal, although the patients often die of intercurrent disease.

BOECK'S SARCOID

This tumor is but briefly mentioned, as it rarely occurs on hands. It is considered a disease or tumor of the reticulo-endothelial system, and in many respects resembles tuberculosis The disease is most commonly manifested in the lungs, although lesions of other organs and tissues may be associated with or independent of pulmonary involvement.

The new growth is composed of epitheloid and giant cells, and replaces normal tissue. On the hand, raised nodular lesions may be present in the skin. A biopsy is diagnostic. Certain bone changes may be present in the small hand bones and are often looked for as a diagnostic aid These consist of condensation of the trabeculae of the phalanges, and small cystic structures, usually near the joints.

Treatment consists mainly of supportive measures to improve the general health X ray therapy has been advocated by some authors. The prognosis is good, although the course of the disease may be prolonged

MUSCLE TUMORS

Introduction and Historical Although it is no doubt possible that tumors may arise from the striated muscle of the hand, no record of such was found in the literature. However, smooth muscle tumors, or leiomyomata may occur in the hand as elsewhere over the body Stout in 1937 made an excellent review of these lesions, and pointed out that up to that time only three articles on the subject had appeared in the English language although the foreign literature was considerable. Credit is given to Forster in 1858 for the first published account of the solitary superficial leiomyoma.

Etiology Although no definite etiology for these tumors is known, they are believed to arise from superficially situated smooth muscle as indicated by their frequency about the perineum and nipples In other locations such as the hand they probably

Fig. 771 Subcutaneous leiomyoma of the dorsal surface of the right middle finger (*Courtesy Stout A. P Amer Jour Cancer*, 29 439 No 3 March, 1937)

arise from vascular smooth muscle or from the erector pili muscles.

Pathology The solitary leiomyoma is generally a small tumor, well encapsulated, rounded in contour, lying just beneath the skin and having a firm to hard consistency

The microscopic picture shows the smooth muscle cells to be irregularly arranged with varying amounts of interposed fibrous connective tissue and varying numbers of blood vessels.

Incidence. Stout collected 95 cases including his own 15, and in this group 19 were on the upper extremity Of his personal cases, two were located on the hand.

The distribution as to sex was about equal, and most of the tumors appear after the thirtieth year

Location. On the extremity the extensor surfaces are the favored locations, and of the two cases on the hand reported by Stout one was on the extensor surface of the long finger and the other on the extensor surface of the thumb They may arise in the skin, or be subcutaneous.

FIG. 772 Granuloma pyogenicum sessile and pedunculated growths. They were removed by surgical excision, an undesirable scar resulting. (Courtesy Michelson, H. E. Arch. Dermat. and Syphilol., 12 498, No. 4 October 1925)

Symptoms. Aside from the presence of the tumor, pain is the only other symptom complained of and is present in only a small proportion of cases. When pain occurs it may amount only to local tenderness, or it may be of more severe paroxysmal type—either spontaneous or induced—and in this respect resembles the glomus tumor

Diagnosis. The diagnosis may be difficult as there is little to distinguish them from other small subcutaneous tumors unless the paroxysmal type of pain is present. They never occur subungually, however

Treatment is surgical excision.

Prognosis. The prognosis for cure is good, as they are benign lesions.

TUMOR FORMING ENTITIES

Pyogenic Granuloma

Introduction and Historical. This benign tumor, because of its clinical appearance, was at one time thought to be due to botryomycotic infection, but since 1902 it has been recognized as a pyogenic granuloma. Approximately one-third of the cases appear on the hand, and for this reason it is given consideration here. A fre-

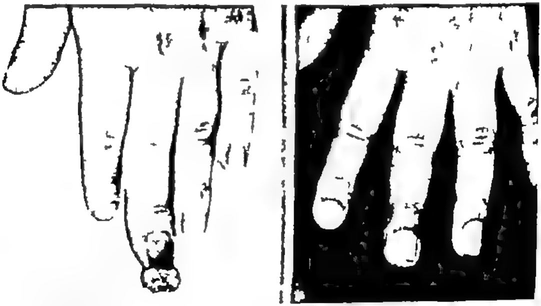


FIG. 773 Pyogenic granuloma (*left*) before and (*right*) after radiation therapy (Courtesy Pack, G T Tumors of the Hands and Feet, St. Louis, The C. V Mosby Co., 1939)

FIG. 774 Pyogenic granuloma which developed in the flexion crease of a finger following a burn. Cured by excision and cauterization of base with silver nitrate and splinting the finger until healed (Wakeman U S. Army photo)

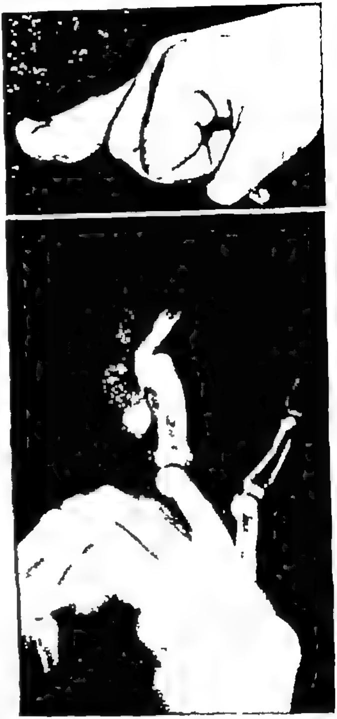


FIG. 775 (*Upper*) Tumor of finger due to foreign body granuloma.

(*Lower*) X ray of tumor showing a single large metallic foreign body and other finely divided foreign material which casts a faint shadow At operation amputation was necessary due to the extensive spread of fine foreign bodies throughout the soft parts. (Wakeman U S Army photo)

quent synonym in use is telangiectatic granuloma.

Etiology The exact cause of this granuloma is not known, but it is believed to arise as a result of trauma or infection, or both. Some authors believe its nature is that of a vascular nevus, while others are of the opinion that *Staphylococcus aureus*, which is usually present, is the sole etiologic factor

Pathology In the gross, these lesions may or may not be pedunculated, but they usually are. They appear as a mushroom like growth, commonly one centimeter in diameter The base is deep in the skin, and is highly vascular The tumor itself is a friable, granulomatous mass which bleeds easily on the slightest contact. Microscopic section reveals inflammatory granulation tissue.

Incidence The lesion is not very common, and statistics as to sex and age are not available.

Location. In a series of 29 reported cases of Michelson 11 occurred on the

hands, and most of these were on the palmar surface of the fingers.

Symptoms. The symptom complained of, in addition to the presence of the un sightly mass, is the frequent bleeding which occurs on the least traumatization.

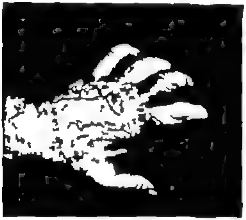


FIG. 776 (*Top*) Paraffinomas. Eight years previously paraffin was injected to obliterate wrinkles in back of each hand, but from irritation made large, red, hard masses.

(*Bottom*) Masses and skin were excised and the denuded area was skin-grafted in each hand.

Diagnosis. This can be made on the appearance of the lesion alone. The short duration, the raspberry red color and the pedunculation all serve to separate it from a possible malignancy Hemangioma must occasionally be considered in diagnosis. An associated complication which may be present is *lymphangitis.*

FIG. 777 Typical appearance of end result of grease gun injury with pitting and scar contracture of finger Photographs taken two years following grease injection and surgical removal of as much as possible. When grease remains in the finger a foreign body granuloma forms. (Courtesy of Dr Tom Cronin, Houston, Texas.)

Treatment. The cure of a pyogenic granuloma is almost as simple as the diag nosis. Effective measures include excision, cauterization, roentgen therapy, and carbon dioxide snow In every instance, the base of the lesion must receive adequate treat ment to prevent recurrence.

Prognosis. The prognosis for cure is good, even though the lesion is apt to recur and require a repetition of therapy

FOREIGN BODY GRANULOMA

Tumors, generally on the volar surface of the hand or fingers, may result from tissue reaction about a foreign body In these cases there is a history of injury, frequently of penetrating type The foreign body, more often than not, cannot be diagnosed roentgenographically due to the material of which it is composed. Microscopically, the foreign body is found to be surrounded by indolent granulation tissue within a dense fibrous tissue capsule Numerous foreign body giant cells are present, and an inflam

matory reaction of moderate severity can be seen There is often a little thin, purulent fluid present, but this is generally sterile on culture.

In addition to the small foreign bodies accidentally introduced, paraffin injected into the hand for cosmetic reasons, or heavy oil or grease blown into the hand, may serve as irritants for the production of granuloma When from cow hair it is called milker's nodule.

Tuberculous Dactylitis

Although infections of the hands have been considered elsewhere in this volume, Chapter 14, tuberculosis of the small bones of the hands may at times simulate bone tumors and, therefore, must be included in differential diagnosis.

Gout

Gout is a medical disease, and under ordinary circumstances would not be considered the cause for tumors of the hand However, what is thought to be a tumor may prove to be gout. These gouty tumors are composed of collections of uric-acid crystals, with the appearance of toothpaste. They are not definitely encapsulated and the crystals show a tendency to deposit about in the tissues Changes are present in the bones and joints The treatment consists of surgical evacuation of these collections of crystals. *It is impossible to remove all by curetting, and they cannot be dissolved out.* On closing, the resulting wounds heal well A strict medical régime as well as colchicein therapy tends to limit recurrence The diagnosis depends upon blood uric-acid elevation and the x ray appearance of the bones.

FIG. 778 (*Left*) Gout. Deposits of sodium urate Periodically patient needs curetting out of deposits. Healing is prompt.
(*Above*) X ray appearance.

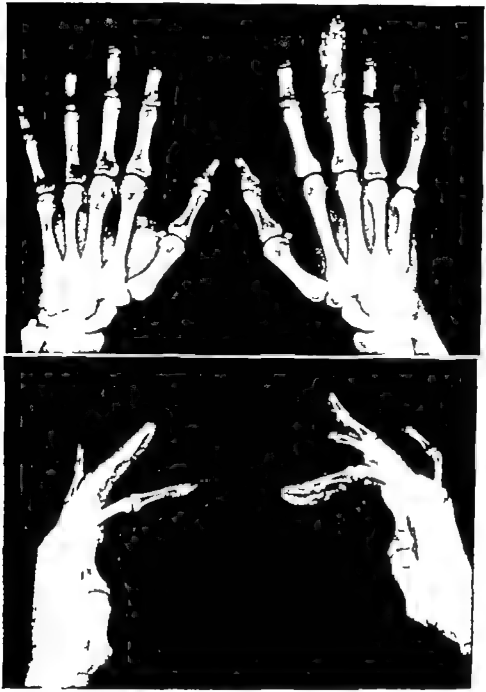


FIG. 779 Case of calcinosis circumscripta. This unusual malady is characterized by deposits of calcium phosphates and carbonates in the soft tissues, usually of the hands and feet, and may be associated with neurovascular disease of the extremity The deposits are more numerous on the volar surface, and may at times suppurate and discharge *The blood calcium is usually normal*, and the condition is differentiated from other tumors by the x ray appearance. (Courtesy of Dr Bradley L. Coley New York. U S. Army Photo)

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